

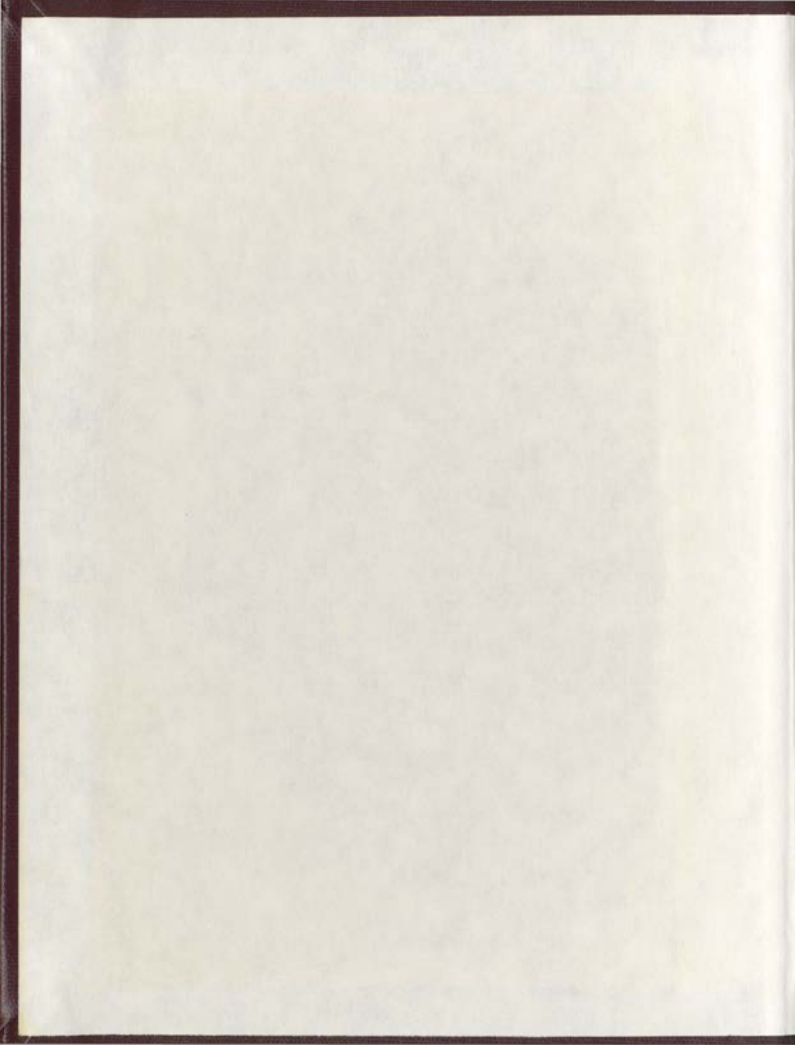
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BIOSTROME COMPLEX,
SOUTHERN LABRADOR

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**LA THÈSE A ÉTÉ
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FACIES ANATOMY OF A LOWER CAMBRIAN
ARCHAEOCYATHID BIOSTROME COMPLEX,
SOUTHERN LABRADOR

by

Steven Hughes, B.Sc.



A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science

Department of Geology
Memorial University of Newfoundland

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St. John's

Newfoundland

ABSTRACT

An archaeocyathid-rich biostrome complex in the middle of the Porteau Formation (Lower Cambrian) of southern Labrador, is divisible into two facies: (1) Oolite Sand Facies, and (2) Biostrome Facies. Stratigraphic and sedimentologic analysis of eight selected areas indicates that the Biostrome Facies was deposited seaward of the Oolite Sand Facies and that the paleoslope sloped towards the south or south-east. The highly irregular nature of the contact between the two facies suggests that salients and recesses occurred within the Oolite Sand Facies and that the Biostrome Facies was deposited on shallow swales within recesses.

Seven lithologies make up the Oolite Sand Facies: skeletal grainstone, oolitic grainstone, mixed oolitic grainstone, mixed peloid packstone, mixed oncolitic grainstone, intraclast grainstone, dolostone and dolomitic siltstone. These lithologies are considered to form an oolite shoal complex consisting of an active shoal, stable sand channels, storm-affected supra-tidal islands, and leeward oolite shoal spillover lobes.

The Biostrome Facies was deposited seaward of, and on shallow swales between, the oolite shoals. This facies consists of five distinct units: Dolomite Mound Unit (BD), Red Mound Unit (BR), Nodular Mound Unit (BN), Oolite Bioherm Unit (BB), and Grey Mound Unit (BG). Each unit consists of two lithofacies: (1) skeletal calcarenite, which

does not vary between units, and (2) moundstone, a new non-genetic rock-type applied to mounds or bioherms of uncertain origin. Five different moundstone lithofacies occur, all of which contain archaeocyathids and sometimes calcareous algae, in a mudstone matrix. The moundstones form mounds, biostromes, and rarely bioherms, all flanked by skeletal calcarenites. Dolomitic Moundstones (BD-1) and Nodular Moundstones (BN-1) formed in relatively deep water, seaward of Red Moundstone (BR-1) which accumulated in lateral contact with the active oolite shoal. Gray Moundstone (BG-1) and Archaeocyathid Bioherms (BB-2) accumulated on shallow, protected swales between oolite shoals. The Archaeocyathid Bioherm lithofacies is flanked by 'quiet-water' oolitic calcarenites (BB-1).

Diagenetic processes which modified the original depositional texture of the moundstones and calcarenites include: bioerosion, dissolution and cementation, neomorphism, dolomitization, silicification, pressure solution (stylolitization), and fracturing. Diagenetic fabrics were formed by these processes operating in a number of diagenetic environments. Micritization, macroborings and facies specific cementation were formed by processes operating in the submarine diagenetic environment. Selective dolomitization occurred in a zone of mixing between meteoric phreatic and marine phreatic waters. Minor dissolution and widespread cementation occurred in the

vadose zone. Fabrics formed in the phreatic environment include extensive stylolitization, dissolution, fracturing, pore-fill cementation, and aggrading neomorphism which includes a transitional micrite-microspar-pseudospar fabric affecting archaeocyathid skeletons. Widespread dolomitization and rare silicification and stylolitization occurred in a late, unspecified diagenetic environment.

The autecology of archaeocyathids, calcareous algae, stromatolites, a new, primitive 'coelenterate', brachiopods, trilobites, hyolithids, echinoderms, and agmata (Salterella), is reviewed and three faunal/floral assemblages are recognised: (1) mound-flanking Skeletal Calcarenite faunal assemblage, consisting predominantly of echinoderms with brachiopods, trilobites, hyolithids and Salterella, (2) mound-dwelling assemblage, consisting predominantly of archaeocyathids and calcareous algae with brachiopods, trilobites, coelenterate, sponges, hyolithids and the ichnogenus Trypanites, (3) coelobitic (cavity dwelling) assemblage, found mainly beneath reticulaminiform archaeocyathids and consisting of pendant calcareous algae, foraminifera, encrusting archaeocyathids, Archaeotrypa, sponges, trilobites, and worms.

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CHAPTER 1: INTRODUCTION

AIMS

Fossil reefs, constructed by different groups of organisms at different times in geologic history, illustrate a wide variety of form and structure (Wilson, 1975). The earliest skeletal reefs are formed by an extinct metazoan, archaeocyathida (Hill, 1972), but such reefs are poorly known and have been rarely described (See Appendix I).

Some of the best exposures of Lower Cambrian archaeocyathid-rich reefs outside of the U.S.S.R. occur in southern Labrador. Here, in the Forteau Formation, two separate archaeocyathid-rich horizons have been recognised (James and Fong, 1976), a lower series of bioherms called the 'patch-reef series' (James and Kobiuk, 1978) and an upper biostrome complex. The purpose of this study is to document the biostrome complex, specifically to:-

- (1) Map the lithofacies of the biostrome.
- (2) Document the paleontological and sedimentological aspects of the biostrome and associated facies to interpret the environment of deposition.
- (3) Outline the diagenetic evolution of the carbonate rocks.
- (4) Determine certain aspects of the paleoecology.

STUDY AREA

Physiography

The study area, southern Labrador, forms the north coast of the Strait of Belle Isle (Fig. 1), at a latitude of approximately $51^{\circ}30'$ and a longitude of $57^{\circ}00'$.

Flat topped hills, bounded by terraced cliffs and wide river valleys form the coastal area and give way inland to rugged Precambrian terrain. The physiography reflects the lithology of the bed-rock and the occurrence of faults. High, steep sea-cliffs such as those between Bradore and L'Anse au Loup (Fig. 4), are formed of Lower Cambrian sandstones (Bradore Formation). These cliffs also form the sides of the major river valleys. The sandstone cliffs give way to a more rolling topography, formed by Lower Cambrian limestone, siltstones and shales of the Forteau Formation, which rises to a maximum elevation of 843 ft. (255 m) above sea-level north-west of Forteau.

Well-developed terracing, formed by differential erosion (Schuchert and Dunbar, 1934) occurs when the Bradore Formation and Forteau Formation are continuously exposed, as to the west of Schooner Cove.

Four major river valleys run parallel to each other in a N.W.-S.E. direction. These U-shaped valleys, containing rivers draining into the sea at Blanc Sablon, Forteau, L'Anse au Loup, and L'Anse au Diable, cut down into the underlying Precambrian crystalline basement. The upland drainage pattern is almost completely controlled by faulting (see below).

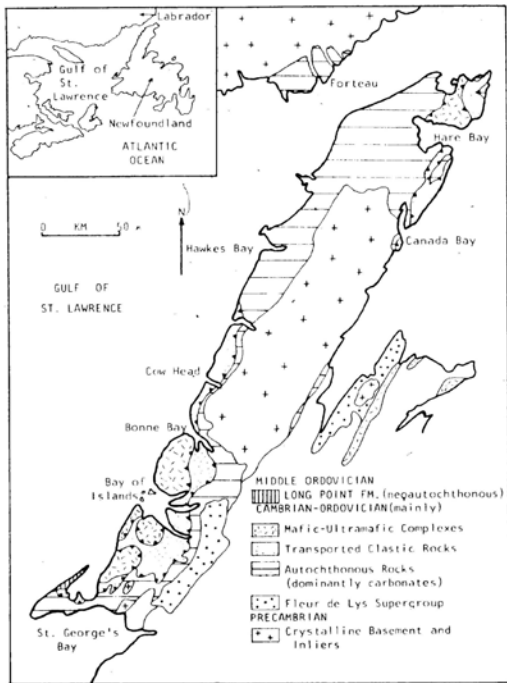


Fig.1: Major geological elements of western Newfoundland and southern Labrador (based on Williams, 1975).

Geologic setting

The rocks under study occur in the upper part of the Forbeau Formation, as exposed in southern Labrador and Québec. Similar rocks also occur in western Newfoundland and these were examined briefly for comparative purposes.

Tectonically, the study area lies west of the western limit of Appalachian deformation but may be considered as the undeformed equivalents of the Lomond Zone (Zone A) of Williams, Kennedy and Neale (1974) now renamed the Humber Zone (Williams, 1976). This zone, lying in western Newfoundland (Fig.1), represents the Lower Paleozoic stable continental margin, parts of which were destroyed by westward transport and subsequent emplacement of oceanic crust (ophiolites) and other allochthonous rocks in Middle Ordovician time (Williams, 1975).

The sedimentary succession (Fig.2) overlies a Precambrian complex of gneisses and schists of Grenville age cut by 900 m.y. granites (Williams et al., 1974). Local developments of plateau basalts, such as the Lighthouse Cove Formation of Belle Isle (Williams and Stevens, 1969), are seen in places to directly overlie Precambrian basement. Most of the sedimentary sequence consists of an eastward thickening, Lower Paleozoic, partly clastic but dominantly carbonate succession (Logan, 1863; Schuchert and Dunbar, 1934; Whittington and Kindle, 1969; Cumming, in press) which can be traced laterally along the length of the Appalachian-Caledonian orogen as far south as Alabama (Palmer, 1971; Williams and Stevens, 1974), and

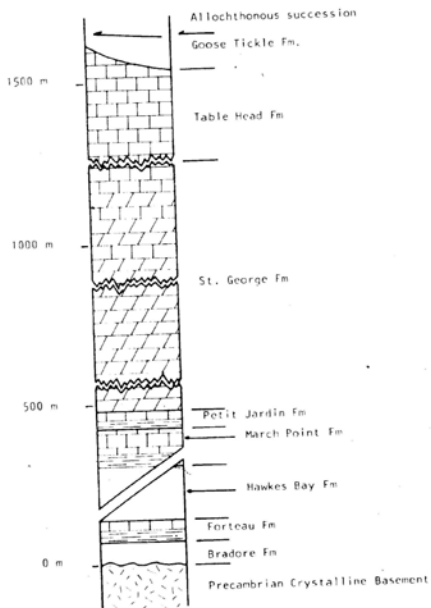


Fig.2: Generalized stratigraphic section of the autochthonous sequence of western Newfoundland (Humber Zone). Modified after Swett and Smit (1972, Fig.1).

northwards into Greenland, Scotland, and Spitzbergen (Harland, 1969; Swett and Smit, 1972).

The sequence in Newfoundland (Fig.2) has been described as two unequal siliciclastic-carbonate megacycles (Levesque, James and Stevens, 1977). The lower cycle is much thinner and of considerably shorter duration, being entirely Lower Cambrian in age, compared with the much thicker upper cycle which ranges from Lower Cambrian to Middle Ordovician. In each case, the cycle commences with a siliciclastic unit, (the Bradore Formation and Hawke Bay Formation, respectively), which grade up into a dominantly limestone sequence (Fordeau Formation in the lower cycle, and the St. George and Table Head Formations in the upper cycle).

Conformably overlying the Table Head Formation (Middle Ordovician is part of a westward transgressing flysch wedge (Goose Tickle Formation) that abruptly terminates the carbonate succession (Williams et al., 1974) and is the highest autochthonous unit seen in W. Newfoundland. The rest of the sequence in the Humber Zone consists of an allochthonous succession of westerly transported rocks, emplaced as structural slices. Sedimentary rocks, including a coarse limestone breccia, are interpreted as being eastern contemporaries of the autochthonous succession, and occur in the lower structural slices, while the higher slices are interpreted as ophiolite suites (Williams, 1975).

The youngest Ordovician stratum seen in this zone is the neoautochthonous Long Point Group (Bergström, Riva and Kay, 1974); a series of biohermal limestones, shales, minor sandstones, and red-beds, of Upper Champlanian-Lower Cincinnati age, (Fahraeus, 1973; Bergström *et al.*; 1974) which were deposited disconformably(?) onto the allochthon (Stevens, 1970).

Detailed Lower Cambrian stratigraphy of southern
Labrador

The area studied in southern Labrador comprises only the basal two-thirds of the thinner, lower megacycle (James and Kobluk, 1978), represented by rocks of the Labrador Group (Schuchert and Dunbar, 1934). The Labrador Group is represented by the Bradore Formation and the lower half of the Forteau Formation, the rest having been removed by erosion (Fig. 3). These rocks outcrop over a 40 km coastal belt from east of Lourdes de Blanc Sablon in Quebec, north-eastwards to West St. Modeste in Labrador (Figs. 8 and 72). Outcrop is continuous in cliff-section except where the major river valleys drain to the sea. Inland the rocks are exposed variably for a maximum distance of 15 km where they are faulted out against Precambrian basement. Outliers occur to the north of the major fault, but are inaccessible by foot.

As the strata in the area are generally flat-lying, the only structural complications result from high angle normal faults of small displacement which are very common. Two sets of faults can be distinguished (see Fig. 72, in pocket) (1) *

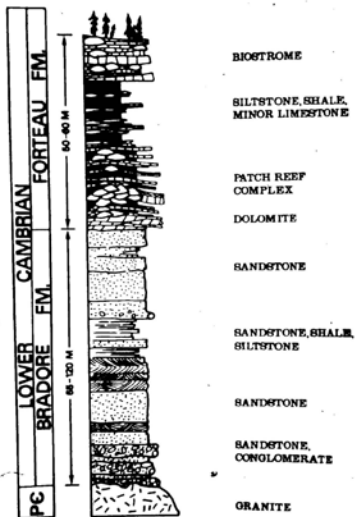


FIG. 1: Generalized stratigraphic section of the Lower-Cambrian sequence in southern Labrador (after James and Leblond, 1978).

those trending N.E.-S.W., (2) those trending E.N.E.-W.S.W. No age relationships can be deciphered between the two sets. A small number of faults have anomalous trends: a N.-S. fault runs through L'Anse au Clair, and two minor N.W.-S.E. faults occur on the Pointe Amour peninsula. Upland drainage is controlled by faulting with all streams following the trend of the faults. The major river valleys flow along Precambrian basement and drain to the south-east. It is not known whether the location of these rivers is fault controlled or glacially controlled.

Bradore Formation

The Bradore Formation (Schuchert and Dunbar, 1934) (Fig. 4) unconformably overlies the Precambrian Grenville basement complex. The contact is a paleosub-aerial surface (James and Kobluk, 1978; Cumming, in press) and can be seen at the base of the cliff to the east of Blanc Sablon. The basal 15 m consists of thin conglomerates and red arkosic sandstones with a bimodal and bipolar current-bedding distribution (Swett and Smit, 1972) characteristic of tidal sand bodies (Reineck and Singh, 1975). The upper 55 m is a more mature arkose to orthoquartzite. The most obvious structure in these sediments are many vertical tubes interpreted as water-escape structures (Cumming, in press) but widely accepted as burrows and called Skolithus linearis. Other trace fossils, including Monocraterion, Dolophichnus, and Lingulichnus, also occur in the Bradore Formation (Pemberton, James and Kobluk,



Fig. 4: Sandstone cliffs of the Bradore Formation exposed to the east of L'Anse au Loup.

1977; Pemberton and Eobluuk, 1978). The only body fossils reported from the sandstone are broken brachiopod shells, believed to be oboloides (Balsam, 1973).

The maximum thickness of the Bradore Formation was given as 285 ft. (86 m) by Schuchert and Dunbar (1934). Cumming (in press) recognises a thickening towards the north-east (West St. Modeste) where he records a thickness of 400 ft. (121 m).

The Bradore Formation occurs in western Newfoundland but is always incomplete. Equivalent strata in western Newfoundland include the Cloud Mountains Formation, (Betz, 1939) in Canada Bay, and the Bradore Formation on Belle Isle (Williams and Stevens, 1969). Swett and Smit (1972) suggest correlatives in Scotland (Eriboll Sandstone), and also East-Central Greenland (Kliffelv Formation).

Forteau Formation

The Bradore Formation is conformably overlain by the Forteau Formation (Schuchert and Dunbar, 1934). These sediments record the first occurrence of carbonate rocks during the evolution of the Lower Paleozoic continental shelf. Only the basal 185 ft. (56 m) occurs in Labrador but the maximum, complete thickness in the Highlands of St. John is 386 ft. (117 m) (Schuchert and Dunbar, 1934).

The sequence (Fig.3) commences with a basal dolomite and shale unit, 3-4 m thick. This is overlain by an archaeocyathid patch-reef complex (Fig.5) which has an average thickness of



Fig.5: Patch-reef facies of the Forteau Formation east of Fox Cove. A patch-reef (centre) is flanked on either side by bedded skeletal calcarenite.



Fig.6: Shales and siltstones of the open-shelf facies, Forteau Formation, exposed in a quarry near to Ten Mile Lake, western Newfoundland.

10 m and has been described by James and Kobluk (1978). They recognise two laterally equivalent facies; a widespread, laterally continuous limestone and shale interbed sequence, termed the 'open-shelf facies', and a complex mosaic of archaeocyathid-rich bioherms and inter-bioherm sediments, termed the 'patch-reef facies'.

The open-shelf sediments are cyclic, each cycle coarsening upwards from shale into nodular limestone, into calcareous siltstone or silty limestone with a maximum thickness of 2 m.

The patch-reef facies (Fig.5) consists predominantly of archaeocyathids and calcareous algae in matrix of lime-mud. These are flanked by off-reef skeletal calcarenites extending out 2 to 6 m from the reef and grading into thin nodular limestones (James and Kobluk, 1978).

The patch-reef complex is overlain by up to 20 m of interbedded calcareous and dolomitic siltstones and shales (James and Kobluk, 1978) which contain a rich and diverse trace-fossil assemblage (Pemberton *et al.*, 1977).

The upper part of the sequence in Labrador consists of a complex of archaeocyathid-rich mounds, surrounded and intercalated with skeletal and/or oolitic calcarenites and lime mudstone, up to 20 m thick (James and Fong, 1976) (Fig. 7). These rocks are the subject of this thesis.

Traced eastwards into Newfoundland, the patch-reef complex of the Forteau Formation grades into black potassium-rich shales (Fig.6) with minor limestones and siltstones (James and Fong, 1976). The biostrome complex is present in St. Margarets



Fig. 7: Archaeocyathid-rich, lime-mud mounds and bedded calcarenites of the biostrome complex, Forteau Formation, L'Anse Amour.

quarry but thins considerably further south in the Highlands of St. John (Schuchert and Dunbar, 1934). To the north on Belle Isle (Williams and Stevens, 1969) and to the south in Bonne Bay (Schuchert and Dunbar, 1934), no archaeocyathids have to date been reported from the Forteau Formation, the sequences being largely argillaceous.

The age of the Forteau Formation in Labrador has been determined using both trilobites and archaeocyathids. Using trilobites, the formation falls into the Bonnia-Olenellus zone and is correlatable with the Sekwi Formation (Upper Elankian) of Fritz (1972). The occurrence of Antagmus sp. and Bonnia columbensis suggests that the Forteau Formation falls into the top of the Bonnia-Olenellus zone while on the basis of the occurrence of Wanneria logani, it falls into the middle of that zone.

Using archaeocyathids, the Forteau Formation is correlatable with the Obrutchev horizon of the Elankian stage of the Siberian platform (Rozanov and Debrenne, 1974).

It may be concluded therefore, using both dates, that the Forteau Formation represents the topmost Lower Cambrian and makes the reefs amongst the youngest archaeocyathid structures so far recorded (James and Kobluk, 1978).

CHAPTER II: METHODS AND TERMINOLOGY

AREAS SELECTED FOR DETAILED STUDY

As a precursor to detailed analysis of the biostrome complex, reconnaissance mapping of the area under study revealed that strata overlying the widespread siltstones and shales above the lower patch-reef series, were either archaeocyathid-rich lime-mudstone or oolitic calcarenites (James and Fong, 1976). Examination of all available outcrops in southern Labrador suggests that these two lithologies along with respective associated lithologies, comprise two distinct facies, herein called: (1) Biostrome Facies (sensu stricto), (2) Oolite Sand Facies, (see Chapter 3).

Lithologic variation between and within the two facies is such that ten areas were selected for detailed study (Fig. 8). Five of these areas are within the Biostrome Facies, four are within the Oolite Facies, and one area combines both facies. The areas selected for detailed study are outlined below. The letter refers to the position of the outcrop on the location map (Fig. 8). (A) Blanc Sablon: This outcrop is the westernmost exposure of the Biostrome Facies and consists of a good vertical section which differs in lithofacies arrangement from the Pointe Amour peninsula. (B) Diversion Reef: This area, which includes the transition between the Biostrome Facies and the

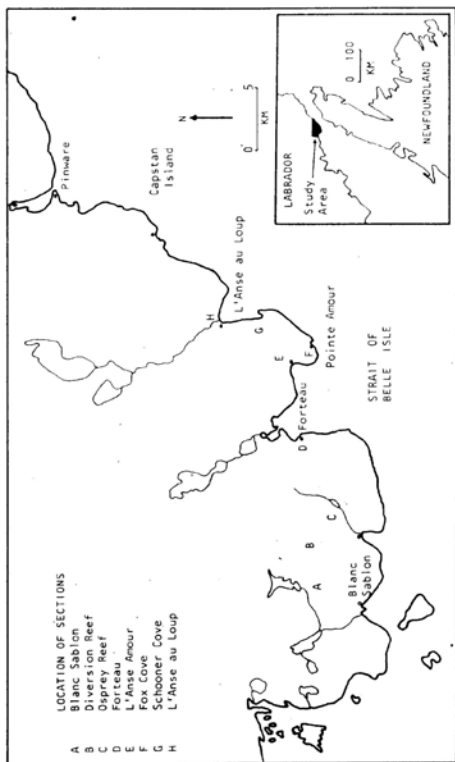


Fig. 8: Location map of southern Labrador.

Oolite Sand Facies, is located approximately 4 km to the north of L'Anse au Clair. The exposures are found along a track but are often covered, giving incomplete sections.

(C) Osprey Reef: This extensive cliff exposure, located to the north of the main road between L'Anse au Clair and Forteau, shows the transition between the two facies.

(D) Forteau: This is the thickest, although poorly exposed, sequence within the Oolite Sand Facies and occurs in outcrops to the south of the main road to the west of Forteau.

(E) L'Anse Amour: This cliff exposure gives a complete vertical section through the Biostrome Facies and extends laterally for almost 3 km. (F) Fox Cove: This is the only

coastal exposure of the Biostrome Facies and is therefore the only location with good bedding plane exposure. (G),

Schooner Cove: An almost complete section occurs in a sequence in which rocks of both facies are present. (H)

L'Anse au Loup: Although very poorly exposed this is the easternmost outcrop of the Oolite Sand Facies that was studied.

The stratigraphy and facies relationships are documented in detail for each locality in the Appendices (A-H) and are discussed in the text.

FIELD METHODS

As the rocks under study constitute a biostromal facies with great lateral variation, just as much emphasis was placed

on lateral relationships within the biostrome as in the vertical succession. More often than not, lateral lithologic changes are as sudden and as frequent as vertical changes.

Where outcrop allowed, photo-mosaics were taken of large exposures to record the lithofacies variation not observable close to the outcrop. Several small-scale maps were drawn to record the horizontal disposition of units in complex areas. About 220 samples were collected and labelled for laboratory examination.

TERMINOLOGY

Due to the many terms used to describe accumulations of fossil remains, and the often misleading or multiple definitions of the individual terms, the following is a brief discussion with definitions of terminology used throughout this thesis. In addition, new terms are introduced where previous terminology is inadequate or non-existent.

The term biostrome has several definitions in the geological literature (see review in Nelson, 1962). It is used in this thesis to describe a diverse suite of rocks, predominantly organic accumulations which form a stratigraphic entity of considerable lateral extent, often measurable in kilometres (cf. Cumming, 1932). Sea-floor relief was present or absent but the unit probably did not form a wave-resistant structure.

This differs from a bioherm which is also an organic accumulation, with or without primary depositional relief, but is not a stratigraphic entity because it is surrounded by rocks of different lithology, and has limited lateral extent, measurable in metres. Bioherms do not form a wave-resistant structure (cf. Cloud, 1952).

A reef is an organic accumulation and does form a wave-resistant structure. Its geometry can be explained using the adjective forms of the terms bioherm and biostrome to qualify the word reef (cf. Nelson, 1962).

The three most used limestone classifications (Folk, 1959; 1962; Dunham, 1962; Embry and Klovan, 1971) were each, in their own way found to be inadequate to describe the rocks under study.

Embry and Klovan (1971) recognised the inadequacy of both Folk's and Dunham's classifications regarding 'reef-like' accumulations (see discussion in Embry and Klovan, 1971; p.733), but retained the useful grain-size discrimination of Folk (1962), and the textural classification of Dunham (1962) in their own classification (Embry and Klovan, 1971; p.734-737) which is widely used today (James, 1978).

Using Dunham's (1962) classification for the allochthonous group of rocks (mudstone, wackestone, packestone, and grainstone), Embry and Klovan introduced a new size fraction of particles larger than 2.0 mm and subsequently added two new names for rocks containing more than 10% of the greater

than 2.0 mm size fraction. The two rock-types are distinguishable on textural terms, in keeping with Dunham, into, floatstone where the large particles are matrix-supported; and rudstone, where the large particles are self-supporting. Embry and Klovan also subdivided the autochthonous organic build-ups into three distinct rock-types, the criteria used being the way in which organisms bound sediment. These rocks are: framestone (organisms constructing a rigid framework and trapping sediment), bindstone (organisms encrusting and binding sediment), and bafflestone (organisms acting as baffles and trapping sediment).

Problems arise with this classification, however, when it is applied to the rocks under study because it is often difficult to clearly differentiate between these three rock-types in the field. The interpretation of bafflestone is particularly difficult and normally requires excellent exposure in three dimensions and considerable interpretation by the worker, as noted by Embry and Klovan (1971, p.737).

For the purpose of this study, a new non-genetic rock-type is proposed; MOUNDSTONE. This is defined as an autochthonous assemblage of skeletons and matrix sediment, commonly mudstone, (but may also be wackestone or packestone) which together have an external geometry of a mound, bios-trome, bioherm or reef. This rock-type has no genetic implications and is used only to describe lithologies of an autochthonous nature where the process of sediment trapping is

obviously not baffling, binding, or a framework, or when the process of formation is in doubt. Moundstone may therefore include rocks that were formed by the post-mortem disintegration and subsequent accumulation of the mud fraction, similar to the mud accumulation of Rodriguez Bank, Florida (Tarmel and Swanson, 1976), which is a process not considered by Embry and Klovan (1971). When the process of sediment accumulation is clear cut, however, then the classification of Embry and Klovan (1971) is used.

Calcarenite sand bodies vary widely in their shape. On a large scale, measurable in tens of metres, four basic morphologies are distinguished (Fig. 9). These morphologies are:

- (1) Wedge: This usually has a flat base, tapering from a maximum thickness at one end to a minimum thickness and eventual disappearance at the other end. The contact with moundstone is interdigitatory although vertical in a broad sense. The calcarenite may be horizontally bedded or may drape off the moundstone at angles of up to 16 degrees.
- (2) Lens: This is usually flat-topped and flat-based over much of its extent, but thins towards the contact with the moundstone. Lateral extent is in the order of tens of metres and the thickness generally less than 2 m. Contact with the moundstone may be horizontal or draped.
- (3) Tabular lens: This is usually flat-topped and flat-based and normally more than 1 m thick. It differs from a normal lens in that the contact with moundstone is vertical (although

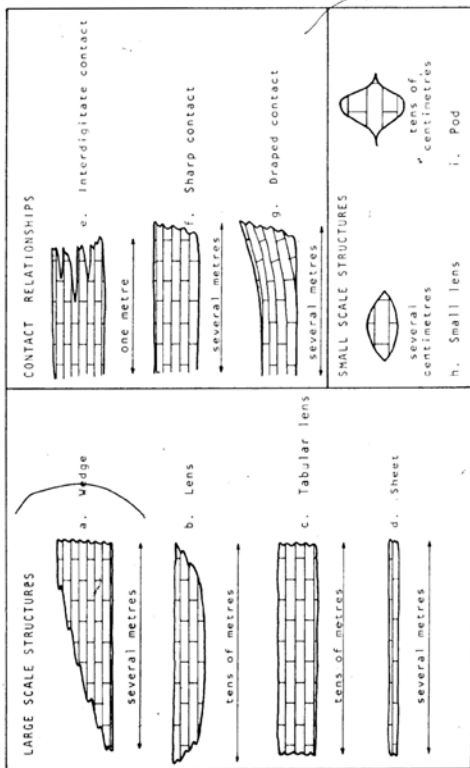


Fig. 9: Sketch illustrating the different geometries of skeletal calcarenite bodies.

interdigitory) and no thinning occurs towards the moundstone.

(4) Sheet: A thin bed that persists over several metres, and tapers out laterally.

On a small scale (measurable in centimetres), two morphologies are recognised. (1) Small lens, where the length of the body is greater than the thickness. (2) Pod, where the height of the body is equal to, or greater than the thickness.

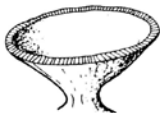
As identification of archaeocyathid taxa is difficult to achieve in the field (Hill, 1972), emphasis was placed on skeletal morphology of the organisms, which shows considerable variation. The basic, undifferentiated archaeocyathid skeleton is a cup (Hill, 1972), and where it is possible to see the shape of the cup, then the following morphotypes are recognised (Fig. 10): (1) Stick (Fig. 10a), the cup has parallel sides throughout the entire height, which is many times greater than the diameter, it is circular in cross-section and may lack an intervalum. This form was later identified as either Archaeocyathus atlanticus or Metaldetes simpliporus, (F. Debrenne, pers. comm., 1978). (2) Cone (Fig. 10b-c). This form is essentially an inverted cone expanding vertically from a basal apex. It is circular in cross-section. Two categories are recognised: narrow cones (Fig. 10b), where the angle of the sides of the cup from the horizontal is more than 45 degrees



a. "colonial" stick-forms
Archaeocyathus atlanticus



b. Narrow cone
Metaldetes profundus



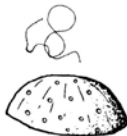
c. Wide cone
Metaldetes profundus



d. Bowl
Metaldetes profundus



e. Funnel
Metaldetes profundus



f. Retilaminiform
Retilamina amourensis

Fig. 10: Sketch illustrating the different archaeocyathid morphotypes.

and wide cones (Fig. 10c), where the angle is less than 45 degrees. In the latter category (although very difficult to observe), if there is no apex, then the morphotype is a bowl (Fig. 10d). If the apex of the cone is elongated over a considerable distance with sides parallel to one another, then a funnel is recognised (Fig. 10e). All the archaeocyathids in the cone category were later identified as Metaldetes profundus (F. Debrenne, pers. comm., 1978).

(3) Retilaminiform (Fig. 10f). This is a new archaeocyathid morphotype and genus, Retilamina amourensis (Debrenne and James, in prep.), which is dome-shaped to sheet-like in form (see description in Chapter V: Paleoecology; Archaeocyathids).

A new organism, found in the Biostrome Facies, is of uncertain zoological affinities but has been tentatively identified as a primitive skeletal coelenterate. This organism is under study by Kobluk and Sorauf (in prep.) and for the purpose of this thesis it is referred to as a coelenterate.

Relative abundance of organisms is given as follows:

Absent, 0% of rock volume; Rare, 0-5%; Present, 5-10%; Common, 10-25%; Abundant, 25-50%; Very Abundant, more than 50%.

PETROGRAPHY

Introduction

Samples from the two facies were slabbed and approximately 150 thin-sections were prepared from representative portions of the slab. The thin-sections were stained with Alizarin Red-S and potassium ferricyanide to differentiate between calcite and dolomite, and to determine the distribution of ferrous iron in the samples (Dickson, 1966; Davies and Till, 1968).

Estimates of percentage of components were made visually as was the approximation of the degree of sorting (poor, moderate, good). The grain size is standardized as follows: mud/micrite (less than 4u), silt (4-100 u), fine sand (100-250 u), medium sand (0.25-0.5mm), coarse sand (0.5-2.0 mm), granule (2-4 mm), pebble (more than 4 mm).

Sedimentary and biogenic structures were noted in the field. Most of the biogenic structures (burrows, etc.) appear to be dolomitized (mottled) and are referred to as bioturbation, the percentage of which was estimated visually.

Components

The major components can be divided into skeletal and non-skeletal categories. Skeletal components occur in various states of preservation, most of which are characteristic for each individual taxon, and are used, along with skeletal morphology, for petrographic identification. Echinoderm plates, trilobite carapaces, Salterella cones, Foraminifera, calcareous algae (Renalcis, renalcid, and

Girvanella), non-calcareous brachiopods, and most archaeocyathid skeletons have retained most of their original skeletal structures and are identified by these along with their characteristic morphologies. Some archaeocyathid skeletons have undergone aggrading neomorphism and sometimes dolomitization (see Chapter IV, Diagenesis) but are still recognisable by their skeletal morphology. On the other hand, hyolithid cones and calcareous brachiopods (the majority of brachiopods present) have all been leached and the voids later filled by a calcite cement. Identification of these components is more difficult in this case and morphology alone must be relied on.

Non-skeletal components, because of their wide variety of forms and hence terminology, are described below.

Mud matrix

The original mud-sized matrix has nearly always been neomorphosed to microspar (up to 25 μ). Relict patches of micrite (less than 4 μ) are rarely seen, usually in shelter cavities or between clumps of calcareous algae.

Ooids

Ooids are the most common non-skeletal component in the Oolite Sand Facies but also occur in Oolitic Calcareenites of the Biostrome Facies. They are preserved in a variety of ways including; a radial-concentric fabric, a pseudospar fabric, and a dolomite fabric. These fabrics are

described in detail below (Chapter IV, Diagenesis).

Composite grains (grapestone)

In the rocks under study composite grains consist predominantly of ooids and echinoderm plates. They are often an important constituent in Oolitic Calcareenites of the Biostrome Facies and occur sporadically in the oolitic and oncolitic grainstones of the Oolite Sand Facies. They are smaller in the oolitic grainstones (750 u) and consist of 2 or 3 ooids embedded in micrite, both in the interstices and around the margin of the grain. They are both larger and more common in the oncolitic grainstone and the Oolitic Calcareenites of the Biostrome Facies. Some of the components are truncated at the margins of the composite grain which is subsequently rimmed with micrite. The composite grains commonly form the nuclei of the oncolites. Following the terminology commonly used (Illing, 1954; Furdy, 1963; Winland and Mathews, 1974;), the composite grains in the rocks under study are probably grapestones.

Peloids

The term peloid embraces all grains constructed of an aggregate of cryptocrystalline carbonate, irrespective of origin (McKee and Gutschick, 1969), thus avoiding genetic implications. It is thought however, that elongate ellipsoidal peloids may represent fecal pellets (Bathurst, 1971). In this study, the only peloids, except for the occasional micritized ooid or skeleton, are very well-sorted, small

(130 x 85 μ), elongated ellipsoids, suggesting a common origin; probably fecal.

Rarely, the peloids are replaced by a single calcite crystal, and more commonly are replaced by dolomite, in the form of either a single rhomb or several smaller rhombs (cf. ooids).

Oncolites and encrusted grains

Oncolites, occurring only in the Oolitic Sand Facies, range in size from 7 mm to a maximum of 35 mm, and have a nucleus which is either a single skeletal fragment or a composite grain. The nuclei are then encrusted with tubules of the blue-green alga Girvanella along with entrapped quartz grains and small skeletal fragments. The oncolites are not deformed and have even laminae around the nucleus (type SS-C of Logan, Rezak and Ginsburg, 1964). They show evidence of more than one period of growth with a maximum of three being observed.

Encrusted grains are defined in this study as grains that are coated on one side only by Girvanella. They never make up more than 5% of the rock volume.

Algal intraclasts

The only observed intraclasts consist of Girvanella tubules with microspar filling the interstices, and range in size from single filaments up to clasts 6 mm long. They vary in morphology from elongated clasts with ragged margins and a high proportion of microspar, to perfectly rounded

balls with lesser amounts of microspar. They differ from oncolites in that they do not possess a nucleus.

Quartz silt

Quartz grains occur only in the silt grade as sub-angular to sub-rounded grains making up to 50% of some of the dolomitic siltstone, and occurring in small proportions throughout the sequence.

CHAPTER III: SEDIMENTOLOGY

LATERAL DISTRIBUTION OF FACIES

Reconnaissance mapping of the study area revealed that the biostrome complex consists of two laterally equivalent facies (see Fig. 72, in pocket): (1) The "Biostrome Facies" consists of a series of archaeocyathid-rich, lime-mud mounds and flanking skeletal calcarenites. (2) An "Oolite Sand Facies" consists of a series of cross-bedded oolitic grainstones, mixed component grainstones, dolostones, and skeletal calcarenites.

That the two facies are lateral equivalents with respect to each other is not in doubt. With the exception of the section of Schooner Cove (Appendix G), all of the outcrops examined in the area consist of lithologies of either the Biostrome Facies or the Oolite Sand Facies. The transition between the two facies can be seen in the large cliff outcrop at Osprey Reef (Appendix C) where the Biostrome Facies passes laterally into cross-bedded oolites of the Oolite Sand Facies (see Fig. 73, in pocket). At Diversion Reef (Appendix B), the Biostrome Facies passes northwards into Salterella-rich oolites, burrowed oolites, dolostones, and calcarenites of the Oolite Sand Facies. The only section where the two facies are interbedded is at Schooner Cove (Appendix G) where archaeocyathid-rich mounds of the Biostrome Facies are inter-bedded with oolitic and oncolitic grainstones of the Oolite Sand Facies.

BIOSTROME FACIES

Introduction

The Biostrome Facies is a complex assemblage of lithologies between 15 and 20 m thick, that occur over a wide area. Using the data from measured sections it is possible to subdivide the Biostrome Facies into several distinct lithological entities. The facies is first divided into UNITS, which are defined as laterally continuous strata bounded by sharp upper and lower contacts. Each unit may contain diverse lithologies but as a whole is regarded as a stratigraphic entity over a large area and can be used in local mapping (but not reconnaissance mapping). Within each unit, LITHOFACIES can be recognised and defined as discrete rock assemblages that are lateral equivalents to one another within a unit. Each lithofacies may contain up to three discrete lithologies which are noted in the description of the lithofacies (see below). The various lithounits are designated as follows:- the Biostrome Facies is designated by an upper case B. Each unit is given identifying upper case letters. Lithofacies are given numbers.

Using this scheme, the Biostrome Facies can be subdivided into five distinct units. Within each of these units, 2 or 3 laterally equivalent lithofacies can be recognised which may contain up to three discrete lithologies.

Generalized Section

A generalized vertical section of the Biostrome Facies is outlined here, and in Figure 11. This is used as a basis for describing the various lithounits. This section is a synthesis of the measured sections described in appendices A-H.

The base of the Biostrome Facies is taken as the first occurrence of moundstone or skeletal calcarenite overlying the siltstones and shales of the open-shelf facies. In most cases, Dolomitic Moundstone (BD-1), with laterally equivalent Black Shales (BD-2) and Skeletal Calcarenites (BD-3) form the basal unit. Sharp lateral contacts occur between archaeocyathid moundstone with dolomite pods, and calcarenite bodies. For contrast, black shales and siltstones grade laterally into both moundstones and calcarenite. This unit is characterized by the large dolomite pods, by interbedded shales, and by a fauna and flora of relatively low density and diversity.

The Dolomite Mound Unit is terminated by a thin but laterally extensive sheet of skeletal calcarenite which is overlain by the Red Mound Unit (BR). This unit consists of archaeocyathid-rich Red Moundstone (BR-1) and flanking Skeletal Calcarenite (BR-2). This unit differs from the underlying Dolomite Mound Unit by its red colour and a fauna and flora of very high density and diversity.

The Red Mound Unit grades upwards into the Nodular Mound Unit (BN) which consists of a black to dark-grey

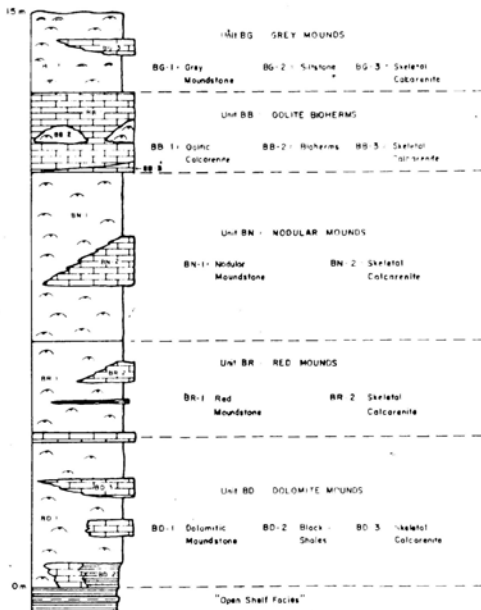


Fig. 11: Generalized section of the Biostrome Facies illustrating the division into five units and five various lithofacies.

Nodular Moundstone (BN-1) with wide-cone archaeocyathids and laterally equivalent Skeletal Calcarenites (BN-2). This unit is characterized by the nodular appearance of the beds and a fauna of low density and diversity.

A sharp contact separates the Nodular Mound Unit from the overlying Oolite Bioherm Unit (BB). Oolitic Calcarenite (packestone to grainstone) is the dominant lithology (BB-1) but contained within the oolites are small Archaeocyathid Bioherms (BB-2).

The topmost unit seen in Labrador is the Grey Mound Unit (BG), which overlies the Oolite Bioherm Unit. This Unit consists of Grey Moundstone (BG-1) flanked by Skeletal Calcarenites (BG-3), and rare Siltstone (BG-2). It is characterized by a grey colour, the abundance of calcareous algae, and the presence of stromatolites.

Description of Lithounits

Five distinct units are recognised within the Biostrome Facies in southern Labrador. Within these five units the two most common lithofacies are: (1) Moundstone, and (2) Skeletal Calcarenite. Siltstone and shale also occur in some of the units but only in minor amounts. The skeletal calcarenite lithofacies are similar in composition throughout the five units so this lithofacies is described only once. On the other hand, the composition of the moundstone varies greatly from unit to unit and these differences are highlighted

in the individual descriptions.

Lithofacies Skeletal Calcarenite: (BD-3, BR-2, BN-2, BG-3, BB-3)

The skeletal calcarenite consists of a white to light-brown resistant wackestone to packestone (common) to grainstone to archaeocyathid floatstone with a packestone matrix (Fig. 12). The calcarenite is composed mostly of echinoderm debris with disarticulated, but unbroken, inarticulate brachiopod shells, and to a lesser extent trilobites and hyolithids. Large archaeocyathid fragments are common adjacent to the moundstones but are rare away from it. Pockets, up to 20 cm thick, consist almost entirely of inarticulate brachiopod shells and are relatively common. Mud matrix comprises from 0-35% of the rock volume.

The calcarenites are massively bedded and for the most part contain no diagnostic physical sedimentary structures. Minor cross-bedding occurs adjacent to the mounds where the calcarenites often dip off the moundstone at angles up to 15 degrees. The cross-bedding always dips away from the mound. (Fig. 25). Other physical sedimentary structures are rare, occurring only locally where they are generally restricted to one horizon (e.g. mega-ripples and ripple-marks in the Dolomite Mound unit at Fox Cove (Fig. 13 and 14). Stylolites are common throughout.



Fig.12: Bedding-plane exposure of skeletal calcarenite which flanks Dolomitic Moundstone (BD-1) at Fox Cove. The small, white areas (bottom, right) are archaeocyathid fragments. Scale is 30 cm long.



Fig.13: Bedding-plane exposure of mega-ripples in skeletal calcarenite (BD-2) at Fox Cove. Hammer is 25 cm long.



Fig.14: Bedding-plane exposure of rippled skeletal calcarenite (BD-2) at Fox Cove.
Scale is 30 cm long.



Fig.15: Dolomitic Moundstone lithofacies (BD-1) at Fox Cove. A pod of dolomite (D) is surrounded by nodular moundstone.
Notebook is 20 cm long.

The skeletal calcarenites occur in a variety of geometries including wedges, tabular lenses, lenses, sheets and channels. They also occur as small lenses within several of the moundstone lithofacies.

Unit BD: Dolomite Mound

This unit occurs in sections only on the Pointe Amour peninsula at L'Anse Amour, Fox Cove and Schooner Cove but is laterally persistent within the peninsula. It is also exposed in the cliff-section at St. Margaret's quarry in western Newfoundland. The rocks are characterized by the presence of pods and small lenses of dolomite.

Three laterally equivalent lithofacies occur within this unit; archaeocyathid moundstone characterized by large pods and small lenses of dolomite (BD-1), coarse skeletal calcarenite (BD-3), relatively minor occurrences of black shale (BD-2).


Lithofacies BD-1: Dolomitic Moundstone

This lithofacies is a light-to dark-grey or green archaeocyathid rich moundstone with a mudstone (common) to packstone (rare) matrix and weathers grey to green to brown with a pitted appearance. The skeletal fraction is dominated by archaeocyathids, most of which are upright. Other skeletal components include the coelenterate which is only locally abundant and is often absent altogether. Subordinate skeletal components include inarticulate brachiopods and trilobites. Detrital quartz silt is very common in this lithofacies.

Stylolites, often delineated by dolomite, are prevalent throughout the moundstone giving it a nodular appearance. A very coarsely crystalline pink calcite commonly fills voids.

Small (several centimetres), skeletal calcarenite lenses contribute approximately 15% by volume to the lithofacies and may have originally contributed more as their margins are also marked by stylolites.

One of the diagnostic features of the Dolomitic Moundstone lithofacies is the occurrence of large (tens of centimetres) pods of finely crystalline dark-green to light-grey dolomite, which weather light to dark brown and buff (Fig.15). The relatively large pods or lenses attain a maximum size of 2.0 x 1.5 m and every gradation is seen in the geometry from a laterally expanded lens to a laterally compressed pod. The contact with the surrounding moundstone is always stylolitized and it is probably because of the intense development of stylolites in the moundstone and absence of them in the dolomite that causes the moundstone to have the appearance of being "wrapped around" the dolomite pods. Several pods show, in weathered cross-section only, distinct laminations and evidence of organic activity in the form of vertical and inclined burrows (Fig.16). Skeletal particles are, however, rare as only one or two upright archaeocyathid cups were found along with the rare skeletal calcarenite lenses.



Lithofacies BD-2: Black Shales

This lithofacies consists of fissile, black shales which grade laterally and vertically into fine siltstones with occasional small lenses of skeletal calcarenite. The shales are of small lateral extent passing laterally, over a few metres, into both skeletal calcarenite and moundstone. The contact between calcarenite and shale is transitional through silts, but the contact between shales and moundstone (seen only at Fox Cove) shows the shales to be draping off the moundstone at angles up to 30 degrees. Small-scale ripples rarely occur in the shales and both skeletal and ichnofauna are absent.

Lithofacies BD-3: Skeletal Calcarenite

Skeletal calcarenites in the Dolomite Mound Unit occur as wedges of limited lateral extent, tabular lenses, and sheets, both extending for tens of metres.

Unit BR: Red Mound

This widespread unit occurs at Blanc Sablon, Osprey Reef, L'Anse Amour and Fox Cove and is distinguished by its red colour and high faunal and floral density and diversity. Although laterally persistent, the unit is often relatively thin and always variable, attaining substantial thickness (more than 15 m) only at Osprey Reef.

Two laterally equivalent lithofacies are distinguishable within the unit: an archaeocyathid rich, red moundstone (BR-1); and laterally equivalent medium to coarse-grained calcarenite (BR-2).

Lithofacies BR-1: Red Moundstone

This lithofacies is a red archaeocyathid moundstone with a mudstone, to rarely packestone matrix containing minor detrital quartz silt and skeletal material (up to 15%). The rock weathers dark red to green, and has a distinctive nodular appearance because of intense stylolization (Fig. 17). No sedimentary structures are present. The skeletal component is dominated by upright archaeocyathids, with narrow cones predominating over stick forms. Retilaminiforms are common and wide cones are rare. Brachiopods are common but trilobites are rare. The coelenterate occurs throughout and calcareous algae is abundant. A coarsely crystalline pink calcite commonly fills primary cavities.

About 10% of the lithofacies consists of small lenses of skeletal calcarenite which are always bounded by stylolites.

Lithofacies BR-2: Skeletal calcarenite

Skeletal calcarenites occur in the Red Mound Unit as wedges of small extent, and as a complex lithofacies mosaic at Osprey Reef (see Appendix C and Fig. 73).

Unit BN: Nodular Mound

This unit is found only on the Pointe Amour peninsula at L'Anse Amour and Fox Cove. It is distinguished by the way that it weathers which gives it a nodular, rubbly, dark-coloured, apparently featureless appearance; and by the relatively low density of archaeocyathids (Fig. 18).



Fig.16: Weathered exposure of a dolomite pod (in BD-1 at Fox Cove) showing laminations and burrows. Scale is in centimetres.



Fig.17: Archaeocyathid-rich, nodular Red Moundstone (BR-1) at Fox Cove. Scale is 30 cm long.

Again two laterally equivalent lithofacies are recognised within this unit; an archaeocyathid-bearing nodular moundstone, and a coarse-grained skeletal calcarenite.

Lithofacies BN-1: Nodular Moundstone

This lithofacies consist of black to dark-grey nodular moundstone with a mudstone and quartz silt (up to 15%) matrix, and weathers dark brown to black with a rubbly appearance. Skeletal elements include rare to common, upright or toppled archaeocyathids with funnel shapes more common than stick forms or cones. Subordinate fauna consists of unbroken, disarticulated inarticulate brachiopods, rare coelenterates and Girvanella, and skeletal debris. The bedding is nodular because of the profusion of stylolites.

Skeletal calcarenite lenses within the moundstone comprise between 10-50% of the volume of the rock and a green to black lime-shale comprises approximately 5% of the total volume.

Lithofacies BN-2: Skeletal Calcarenite

Skeletal calcarenite occurs only as wedges with a maximum lateral extent of 20 m.

Unit BB: Oolite Bioherm

This unit occurs only in sections measured on the Pointe Amour peninsula at L'Anse Amour, Fox Cove, and Schooner Cove. Three lithofacies are recognised, an archaeocyathid moundstone with a mudstone matrix forming small bioherms (BB-2), oolitic calcarenite (packstones-grainstones) (BB-1),

and skeletal calcarenite (BB-3). The unit is distinguished by the presence of oolitic grainstones, the dominance of calcarenite over moundstone, and the occurrence of moundstone in small, discrete bioherms.

Lithofacies BB-1: Oolitic Calcarenite

This lithofacies consists of a diverse suite of oolitic packstones and grainstones (Fig. 18). The lithofacies includes clean oolitic grainstones; a common occurrence of oolitic packstones (15% mud matrix) with irregularly coated ooids, grapestones, oolitically coated grains, and local developments of skeletal stromatolites; a very coarse-grained skeletal oolitic grainstone where ooids occur with brachiopods, trilobites, occasional archaeocyathid cups and Salterella cones.

The size of the ooids varies greatly and fining upwards sequences occur, reflected in both the size of the ooids and the proportion of skeletal material. No other sedimentary structures occur although sharp contacts within the sequence are common. Selective dolomitization of ooids occurs and stylolites are present.

Lithofacies BB-2: Archaeocyathid Bioherms

Red to grey to green archaeocyathid moundstone bioherms with a mudstone to packstone matrix occur locally throughout the unit. The bioherms have a flat to slightly convex base and are strongly convex at the top. The maximum thickness is at the centre of the structure and tapers away

on both sides until the structure pinches out altogether. The contact with the oolites is interdigitatory. No sedimentary structures are observed. Retilaminiform archaeocyathids are abundant at the base occurring with calcareous algae but are replaced upwards by narrow cone archaeocyathids with thick walls, and sticks. Brachiopods, trilobites and calcareous algae are present. Skeletal debris forms up to 20% by volume of the matrix. Styolites are present.

Lithofacies BB-3: Skeletal Calcarenite

Skeletal calcarenites in the Oolite Bioherm Unit occur as laterally impersistent lenses extending laterally for up to tens of metres.

Unit BG: Grey Mound

This unit occurs in sections measured at Blanc Sablon, L'Anse Amour and Fox Cove, where it forms the highest beds seen. It is distinguished by a predominantly light-to dark-grey colour, the abundance of calcareous algae, and the occurrence of non-skeletal and skeletal stromatolites. Compared with other units it is relatively poorly exposed so the lateral extent and equivalent rock-types are poorly known. Three laterally equivalent lithofacies can be recognised, however, an algal/archaeocyathid grey moundstone (BG-1), medium to coarse-grained skeletal calcarenite (BG-3), and calcareous siltstone (BG-2).

Lithofacies BG-1: Grey Moundstone

This algal-archaeocyathid moundstone is light-grey in colour and has a mudstone matrix, containing up to 30% quartz silt, and weathers light-to dark-grey with a pitted surface (Fig. 19). Bedding and other sedimentary structures are absent. Archaeocyathids are rare to abundant, both upright and overturned, and are generally smaller in size than in other units. Cones, stick-forms, and reticulaminiforms are present. Brachiopods are present, calcareous algae and both skeletal (*Girvanella*) and non-skeletal stromatolites are widespread. Stylolites, although present, are not as common as in the other units.

Lithofacies BG-2: Siltstone

This lithofacies consists of a fine-grained, slightly calcareous siltstone which occurs only at the base of the unit in one outcrop, as the lateral equivalent to the skeletal calcarenite and in turn the moundstone. The contact between the silt and the calcarenite is transitional, one grading into the other over a short distance (less than 10 m). The siltstone is laminated and shows ripple-laminations as well as interference ripple-marks. No skeletal fauna is observed but there is a profuse ichnofauna with well preserved burrows, tracks and trails. This siltstone is very similar to that found in the open-shelf facies underlying the biostrome complex.

Lithofacies BG-3: Skeletal Calcarenite

The skeletal calcarenite of the Grey Mound Unit occurs



Fig.18: Cliff-section of Nodular Moundstone (BN-1) overlain sharply by bedded Oolitic Calcarenites (BB-1) at Fox Cove.



Fig.19: Cliff-section exposure of Grey Moundstone (BG-1) and flanking skeletal calcarenites (BG-2) at Blanc Sablon. Range pole is graduated in 20 cm increments.

as small wedges, tabular lenses, and as a channel-like structure at Blanc Sablon which is described in detail in Appendix A.

OOLITE SAND FACIES: DESCRIPTION OF LITHOLOGIES

Introduction

In contrast to the Bostrome Facies, the Oolite Sand Facies is very poorly exposed and in only three areas can sections be measured (see Appendices C, D, H). Using the data from these sections, augmented by petrographic analysis, a total of seven lithologies can be recognised; (1) Skeletal grainstone, (2) Oolitic grainstone, (3) Mixed oolitic grainstone, (4) Mixed peloid packstone, (5) Mixed oncolitic grainstone, (6) Intraclast grainstone, (7) Dolostone-dolomitic siltstone.

Lithologies are named using the most abundant component, and depositional texture (after Dunham, 1962; Embry and Klovan, 1971) but other features were also taken into account in their description, e.g. sorting, grain size, and physical and biogenic structures. The lithologies are summarized in Table I and are described below.

Lithologies

(1). Skeletal grainstone

The skeletal grainstones are poorly to moderately sorted and range in size from silt through to granule grade. The skeletal components, in order of decreasing importance are; echinoderm plates, Salterella cones, trilobite carapaces,

hyolithid shells, brachiopod shells, and tubules of the blue-green algae Girvanella. Less than 15% of the components are non-skeletal allochems; ooids, peloids, quartz silt, and encrusted grains. The sediments are generally bioturbated with dolomite mottle occupying up to 20% of the rock. This calcarenite differs from the skeletal calcarenite of the Biostrome Facies in that it is bioturbated, often contains Salterella cones, encrusted grains, a wider variety of allochems, and contains no mud fraction.

(2). Oolitic grainstone

The oolite grainstones are well-sorted and consist predominantly of coarse, sand-grade ooids (up to 90% of components), with minor amounts of non-skeletal components, quartz silt, and composite grains. In some samples skeletal components, mainly echinoderm plates, trilobites, and Salterella, make up to 20% of the total components. Planar cross-bedding is common (Fig. 20).

(3). Mixed oolitic grainstone

The mixed oolitic grainstone is a moderately sorted, medium to coarse-grained, sand-size grainstone consisting mainly of ooids (40-80%), but with large proportions of other components, in this case peloids and skeletal material (echinoderms, trilobites, and brachiopods).

(4). Mixed peloid packestone

The mixed peloid packestone is a poor to moderately sorted (mud to granule-size grade) packestone with peloids forming the main component (40%), but with a large skeletal



Fig.20: Cross-bedded oolitic calcarenites of the Oolite Sand Facies, Osprey Reef.
Scale is 30 cm long.

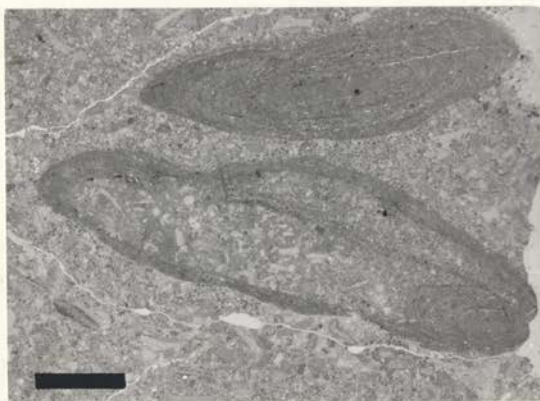


Fig. 21: Photomicrograph (plane light) of the mixed oncolite grainstone lithology showing two large oncolites (one with three periods of growth) in a grainstone matrix of ooids, peloids, echinoderm plates and other skeletal material.
Scale bar is 5 mm.

content (40%) of Salterella cones, echinoderm plates, trilobites, hyolithids and Girvanella. About 10% of the rock consists of dolomitic mottling (probably bioturbation).

(5). Mixed oncolitic grainstone

The mixed oncolitic grainstone is a poorly sorted, silt to pebble grain-size grainstone composed of Girvanella oncolites, with lesser, but significant proportions of ooids, peloids, quartz silt, and composite grains (Fig. 21). Skeletal components include Salterella, echinoderms, hyolithids, and trilobites. Up to 20% of the rock-volume is dolomite mottling (bioturbation).

(6). Intraclast grainstone

The intraclast grainstone is a poorly sorted, silt to pebble grade grainstone consisting almost entirely of algal intraclasts, either as rounded balls or as elongated clasts with ragged edges (Fig. 22). The intraclasts consist of Girvanella tubules with no apparent nuclei. Skeletal (unidentified) grains encrusted with Girvanella contribute less than 5%. One-third of the rock-volume consists of very coarse spar which fills in the primary porosity, and geopetal microspar.

(7). Dolostone-dolomitic siltstone

This lithology ranges from 100% crystalline dolomite with a very sucrosic texture, to a dolomitic siltstone consisting of 50% crystalline dolomite and 50% detrital quartz silt. Skeletal components occur sporadically but are always

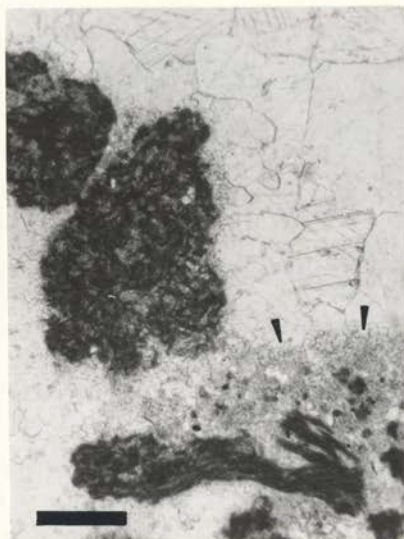


Fig.22: Photomicrograph (plane light) of the intraclast grainstone lithology showing both rounded and elongate, ragged clasts, both consisting entirely of Girvanella tubules. Note geopetal sediment (arrowed) above ragged clast and the abundance of pore-fill cement. Scale bar is 0.45 mm.

partially dolomitized. Sedimentary structures include horizontal, parallel, and ripple lamination. About 10% of the rock is bioturbated.

DISCUSSION

Correlation

Geologic mapping of the area studied indicates that the Biostrome Facies and the Oolite Sand Facies are lateral equivalents and represent two completely different sedimentary regimes which occurred simultaneously at the time of deposition (see Fig. 72, in pocket). Contacts between the two facies are either abrupt and can be walked out along strike (as at Osprey Reef, Appendix C; and Diversion Reef, Appendix B) or are inter-digitatory (as at Schooner Cove, Appendix G) with rocks characteristic of each facies alternating in a vertical sequence. In other measured sections, using the top of the open-shelf facies as a datum, the sequences consist wholly of either the Biostrome Facies or the Oolite Sand Facies.

Within each facies lithologic correlation is extremely difficult due to the lateral variation of lithofacies and lithologies. This is exemplified in the Oolite Sand Facies at Diversion Reef (Appendix B) where incomplete exposure and lateral variation of lithologies make correlation impossible. Such variation indicates that rapid lateral changes in environmental conditions occurred in the sedimentary regime at the time of deposition. It has been established,

however, that the Oolite Sand Facies consists of seven distinct but gradational lithologies, each characteristic of the environment in which it was deposited so the general picture of the sedimentary environment can be formulated. Differences between the five units of the Biostrome Facies are real, although slight, but could be used for detailed mapping only because of the rapid lateral changes. All the units are similar in terms of texture (they are all moundstones), most have identical flanking skeletal calcarenites, and all contain archaeocyathids. The major differences between the units are colour of sediment, density & diversity of organisms, morphologies of archaeocyathids, and diversity of calcareous algae.

The Dolomitic Moundstone (BD-1) is characterized by the presence of dolomite pods at certain localities. There is a relatively low density and diversity of organisms while calcareous algae is absent.

The Red Moundstone lithofacies (BR-1) differs greatly from the Dolomitic Moundstone by being red in colour, having the highest density and diversity of organisms, and containing abundant calcareous algae.

The Nodular Moundstone lithofacies (BN-1) is very similar to the Dolomitic Moundstone but has more shales and a lower density and diversity of organisms.

The Grey Moundstone lithofacies (BG-1) is characterized by its grey colour and by the abundance of calcareous algae and both skeletal and non-skeletal stromatolites.

The Archaeocyathid Bioherm lithofacies (BB-2) is internally similar to the Red Moundstone but differs by forming discrete bioherms within Oolitic Calcareenites (BB-1).

On a broad scale, the five units were probably deposited in a similar environment with slight differences in parameters (depth, light, energy, etc.) producing the characteristic features of the units.

The units within the Biostrome Facies can be correlated locally on the Pointe Amour peninsula between L'Anse Amour, Fox Cove, and to a certain extent Schooner Cove. This gives an indication of the true biostromal nature of the facies. On a larger scale, however, lateral variation of measured sections prevents precise correlation, but taking the top of the open-shelf facies as a datum, it is considered that the sections are contemporaneous.

The lateral distribution of the Red Mound Unit (BR), the most widespread of the five units, illustrates the problems of correlation and emphasizes the lateral variation within the Biostrome Facies. At Blanc Sablon (Appendix A), Red Moundstone is only 1.30 m thick and is both underlain and overlain by rocks of the Grey Mound Unit (BG). About 8 km to the east at Osprey Reef (Appendix C), the Red Mound Unit exceeds 15 m in thickness and occurs in lateral contact with the Oolite Sand Facies. A further 10 km to the east the Red Moundstone is 2.30 m thick at Fox Cove (Appendix F) where it is underlain by Dolomitic Moundstone

(BD-1) and overlain by Nodular Moundstone (BN-1). Less than 5 km to the north-east at Schooner Cove, however, the Red Mound Unit does not occur at all, possibly replaced by rocks of the Oolite Sand Facies.

Other units; the Dolomite Mound (BD), Nodular Mound (BN), and Oolite Bioherm (BB), are restricted to, but laterally persistent within, the Pointe Amour peninsula. Most of the section at Blanc Sablon consists of rocks of the Grey Mound Unit. This unit is only seen at the top of the section at Fox Cove and L'Anse Amour and is inter-bedded between oolitic calcarenites at Schooner Cove. This further illustrates the difficulty of both local and large scale correlation within the Biostrome Facies.

Depositional Environment of the Oolite Sand Facies

Each of the seven lithologies documented in the Oolite Sand Facies have diagnostic features which are used to formulate an appropriate environment of deposition. The lithologies described earlier are discussed in turn below.

(1) Skeletal grainstone

The grainstone texture of this lithology and the worn and often broken nature of the components suggests an environment of constant wave or current action where mud is removed by winnowing (Wilson, 1975). The skeletal content of the calcarenites suggests a shallow, sub-tidal origin of the components (Heckel, 1972). Such sediments are accumulating today in the Persian Gulf and the Bahamas in a position

seaward of oolite tidal shoals (Heckel, 1972; Purser, 1973; N. James, pers. comm.). The stratigraphic occurrence of the skeletal grainstone with oolites in the rocks under study would support a shallow, sub-tidal, agitated environment seaward of an oolite sand shoal.

(2) Oolitic grainstone

By comparison with modern occurrences of well-formed (uniformly coated) ooids, the oolitic grainstones are interpreted to have formed in well-agitated inter-tidal or shallow sub-tidal environments (Bathurst, 1971). The occurrence of herring-bone cross-bedding at Osprey Reef (Appendix C) indicates current reversal and infers an inter-tidal origin (Reineck and Singh, 1975) although measurement of current direction from all cross-beds at Osprey Reef indicates a polymodal direction (Fig. 23). The oolitic grainstones are considered, therefore, to have formed in inter-tidal or shallow sub-tidal, high energy oolite tidal shoals, similar to environments described from the Bahamas (Ball, 1967; Bathurst, 1971) and the Persian Gulf (Loreau and Purser, 1973).

(3) Mixed oolitic grainstone and (4) Mixed peloid packstone

No sedimentary structures were observed in either of these lithologies so analogy with modern environments must be relied on to interpret the depositional environment. Skeletal, peloid calcarenites are accumulating in inter-tidal

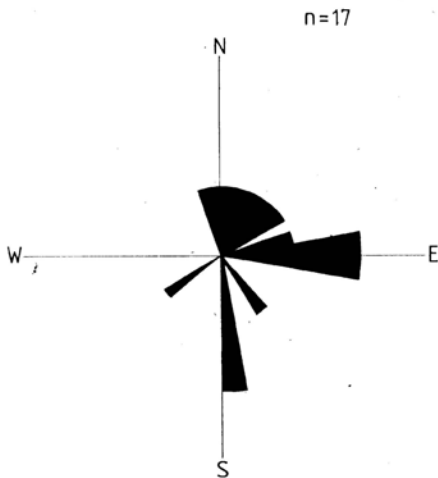


Fig. 23: Rose diagram of inferred paleocurrent directions from cross-bedded oolites, Osprey Reef.

zones within oolite bars or in shallow, protected sub-tidal zones behind tidal oolite shoals along the Trucial Coast of the Persian Gulf (Loreau and Purser, 1973; Purser and Evans, 1973). As there is no indication of inter-tidal structures and the skeletal components suggest a sub-tidal origin, the shallow, protected sub-tidal environment behind an oolite shoal is preferred. The mixed oolitic grainstone can be considered gradational with the mixed peloid grainstone and formed in a similar environment although closer to the actual source of ooids.

(5) Mixed oncolitic grainstone

Diagnostic components in this lithology are composite grains (grapestone), and oncolites. Grapestones occur in areas of uneven turbulence (alternating intervals of cementation and agitation), low sedimentation rates and high water circulation rates (Winland and Mathews, 1974). Oncolites form in a variety of environments, some favouring high-energy and continual motion (Ginsburg, 1960; Logan *et al.*, 1964), some shallow-water and moderately high-energy (Wilson, 1975). They are also found in sheltered, inter-tidal areas and in stable sand channels between mobile oolite shoals (Bathurst, 1971). As several of the oncolites show periodic growth, with grapestones forming the nuclei, a high-energy, continual motion environment is not favoured. A shallow, sub-tidal, medium-high energy environment with slow deposition and fluctuating turbulence is favoured. This environment may

occur in stable sand channels between oolite shoals (Bathurst, 1971).

(6) Intraclast grainstone

The fragmented (ragged) to rounded nature of the Girvanella clasts suggests that they have been ripped up from a nearby source, probably an algal (Girvanella) mat, and redeposited. The degree of roundness may reflect different lengths of time in the transport regime. The geopetal microspar may have been secondarily introduced (vadose silt?) as it occurs in leached skeletons now filled with cement, implying that the skeleton was leached before deposition of the silt. The intraclast grainstone may therefore, be a storm deposit, formed in an environment usually above sea-level and only submerged during storm flooding. The rapid deposition would explain why all of the clasts are not rounded in what would appear to be a high energy deposit (a grainstone texture).

(7) Dolostone-dolomitic siltstone

The environment of deposition of this lithology is also not clear. The occurrence of dolostones in a facies which is, for the greater part, undolomitized may suggest that dolomitization was early, possibly penecontemporaneous with deposition. Recent penecontemporaneous dolomite is recorded from the supratidal environment, forming inches above the high-tide level (Shinn et al., 1965). The dolostones under study are, for the most part, structureless but

are sometimes laminated, burrowed, and rarely ripple-laminated. Recent supra-tidal dolomite crusts are similar, being for the most part structureless with occasional laminations, burrows, and mud cracks, (Shinn et al., 1965). No mud cracks were observed in the dolostones but this may have been due to the badly weathered nature of the outcrop. The dolostones are considered, therefore, to have formed in a dominantly supra-tidal environment which was periodically submerged (during storms?) to accommodate the quartz silt, and produce rare ripple laminations.

The seven lithologies described and discussed can all be attributed to formation within an oolite shoal complex, and can be compared to modern day environments, particularly in the Persian Gulf (Loreau and Purser, 1973; Purser and Evans 1973). Lack of outcrop prevents detailed discussion of the geometry of the oolite shoal although a general model can be presented.

Cross-bedded oolitic grainstones formed under optimum, high-energy conditions for ooid growth, probably in the inter-tidal or shallow sub-tidal environments. In between individual shoals, mixed oncolite grainstone accumulated slowly in stable sand channels. The oolite shoals built up sufficiently to become emerged above the high-tide level where supra-tidal dolomite formation occurred. This environment, on the crest of the shoals, was periodically inundated by storm floods, possibly also producing the intraclast grainstone. Winnowed, skeletal grainstones occurred seaward

of the oolite shoal in a medium-energy, shallow, sub-tidal environment, where a wide variety of organisms flourished in well-aerated waters. In quieter areas, behind the oolite shoals the mixed oolitic grainstones and mixed pel-oid packstones accumulated as oolite shoal spillover with mixed oolitic grainstones occurring closer to the shoal.

Depositional Environment of the Biostrome Facies

Essentially, two major lithofacies occur within the Biostrome Facies; skeletal calcarenite, and moundstone. Variation is considerable within the moundstone but the calcarenites which flank the mounds are essentially the same and indicate that the variation in environmental parameters which controlled the distribution of organisms which contribute sediment to the calcarenite lithofacies was not great.

Diagnostic characteristics of a particular depositional environment are lacking in the calcarenities. They probably formed under sub-tidal conditions, almost certainly quiet-water as there is a lack of fragmentation or wear of the skeletal components, and there is a mud content of up to 30% which was not winnowed out. This is the opposite situation to the skeletal calcarenite of the Oolite Sand Facies which is a grainstone and often has fragmented and worn skeletal components. This suggests that the skeletal calcarenite of the Biostrome Facies accumulated in a lower energy, more protected environment, possibly below the wave base.

For the most part, the skeletal calcarenites are massive bedded and do not contain any sedimentary structures. Where sedimentary structures do occur they are restricted to a single horizon as at Fox Cove (Appendix F) where mega-ripples (with wavelengths of more than 1 m) can be traced in a single bed for more than 300 m (Figs. 13 and 70). Mega-ripples are generally indicative of very high-energy (Reineck and Singh, 1975), but as this is the only indication of high-energy, the mega-rippled horizon is interpreted as storm generated. The fact that the mega-ripples are preserved and have not been reworked is a possible indication of the prevailing low energy conditions. Ripple marks (symmetrical, asymmetrical and interference) are often associated with calcarenites and siltstones at the base of the Biostrome Facies adjacent to the contact with the open-shelf facies (e.g. Blanc Sablon, Appendix A; Fox Cove, Appendix F; L'Anse Amour, Appendix E), but the occurrences are regarded as indicative of the sedimentary regime of the open-shelf facies and that the contact between the two is really transitional.

The origin of the ooids in the Oolitic Calcarenite lithofacies (BB-1) merits special attention. A proportion (20-30%) of the ooids show a high degree of asymmetry of the oolitic layers about the nucleus (Fig. 24), and sometimes the nucleus protrudes through incomplete coatings. The incomplete coatings about the nucleus so are not the re-

sult of abrasion, and although the coatings have a scalloped appearance, it is the result of differential growth of the layers.

Ooids are generally considered to be generated in a high-energy environment (Bathurst, 1971). The irregular ooids, however, are similar to those formed today in a low-energy environment in the Laguna Madre, Texas and described as 'quiet-water' ooids (Freeman, 1962). The mud content (approximately 15% of rock volume) of these oolitic packstones, and the absence of sedimentary structures indicative of high-energy conditions, supports the origin of these ooids in a relatively quiet-water environment. The occurrence of small, archaeocyathid bioherms and small, skeletal (Girvanella) stromatolites embedded within the 'quiet-water' ooids suggest normal marine conditions as regards circulation, salinity, etc. The presence of normal ooids, however, suggests that an active oolite shoal was close by and probably acted as a source for the majority of ooids, some of which then grew irregular coatings in the lower-energy environment.

The skeletal calcarenite lithofacies throughout most of the five units is interpreted therefore as having formed under normal marine, relatively quiet-water conditions, but probably shallow-water enough to be affected by storms.

As the archaeocyathid mounds are always found in lateral contact with the skeletal calcarenites, then a similar environment (low-energy, shallow marine) is interpreted for the mounds as well. Supporting evidence for relatively quiet water conditions is the high percentage of upright archaeocyathids in all of the moundstone lithofacies and supporting shallow water is the occurrence of calcareous algae in some of the moundstones. The dominance of suspension feeders (archaeocyathids, echinoderms, brachiopods, etc.) and presence of silt-grade quartz in both the moundstones and calcarenites suggests however, that the water was continuously turbulent to some degree, with currents powerful enough to keep silt in suspension. It is possible, however, that the silt may have been of windblown origin.

The draping (up to 15 degrees) of the skeletal calcarenite beds off the mounds implies that the mounds formed topographic highs on the sea-floor although field observations suggest that this relief was in the order of only one or two metres. The elevation of the mounds (not always seen) may have been induced by the baffling of mud by archaeocyathids, or early cementation of the mounds, or a combination of both.

Differences between the five moundstone lithofacies are sufficient for more precise environments of deposition to be suggested. These differences, along with stratigraphical evidence can be used to suggest a paleogeographical model.

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The Dolomite Mound Unit (BD) is restricted to the Pointe Amour peninsula and consists of low elevation, but laterally extensive mounds flanked by skeletal calcarenites (Fig. 25), and rarely shales. The mounds are devoid of calcareous algae and have a low density and diversity of archaeocyathids and other organisms. The absence of calcareous algae, which is commonly associated with archaeocyathids elsewhere in the sequence, may suggest deposition below the photic zone. The exact depth of deposition is not known, but the occurrence of calcarenites interpreted as storm-induced deposits interbedded with calcarenites indicating prevailing low energy conditions suggests that deposition probably occurred below wave-base, but in water shallow enough to be affected by storms. The dolomite pods are interpreted as being initially small areas of mud occurring within, but differing from, the mound sediments (see discussion in Chapter IV, Diagenesis). The mounds supported a different fauna (as evidence by trace fossils which do not occur in the moundstones) and probably occurred in shallow, protected depressions within the archaeocyathid mounds. The Dolomite Unit contains shales, has a high silt content, and overlies and is in part laterally equivalent to the siltstones and shales of the open-shelf facies. It probably represents the initial stage of the development of the biostrome complex. The widespread Red Mound Unit (BR) consists of a complex lithofacies mosaic



Fig.24: Photomicrograph (plane light) of irregularly coated ooids in the Oolitic Calcarenite (BB-1). Note incomplete coatings which give the scalloped appearance of ooids. Scale bar is 0.45 mm.



Fig.25: Contact relationships between Skeletal Calcarenite (BD-2) and Dolomitic Moundstone (BD-1) at Fox Cove. Skeletal calcarenite thins towards, and is replaced laterally by, moundstone. Structurally, the strata are flat-lying but the calcarenite drapes off the moundstone at about 12° . Note minor cross-bedding (arrowed) associated with the angle of drape. Scale (centre left) is 30 cm.

of laterally restricted (tens of metres), low elevation mounds and flanking skeletal calcarenites. Calcareous algae, and to a lesser extent non-skeletal stromatolites, are abundant in the Red Moundstone (BR-1) implying deposition within the photic zone. The high density and diversity of archaeocyathids and other organisms suggests a well-aerated environment. The thickest development of the Red Mound Unit occurs at Osprey Reef (Appendix C) where it is in lateral contact with cross-bedded oolites. The channeling of the moundstones by skeletal calcarenites (Fig. 26), along with their association with cross-bedded oolites would suggest that deposition of the Red Mound Unit was under relatively high-energy conditions, possibly within the surf zone.

The red colour of the moundstones poses a problem as marine red beds are rare in the stratigraphic record. In order for them to be preserved, either continuous oxidizing conditions are needed during deposition, or rapid burial must occur before reduction takes place (Heckel, 1972). In view of the shallow water, well-oxygenated, high-energy environment of the Red Moundstone lithofacies, it is more likely that the sediments remained in a continuously oxidizing condition during deposition and burial.

The Nodular Mound Unit (BN) is restricted to the Pointe Amour peninsula and consists of indistinct, but laterally extensive, low relief mounds flanked by wedges of skeletal cal-



Fig.26: Red Moundstone (BR-1) channeled by Skeletal Calcareenite (BR-2) at Osprey Reef. Note irregular outline of erosive contact, and truncation of archaeocyathid skeleton (arrowed) in the moundstone.
Scale is in centimetres.

carenite at L'Anse Amour (Appendix E). At Fox Cove (Appendix F) however, smaller but still indistinct mounds are recognised by; an increase in the density of archaeocyathids, an increase in the proportion of skeletal calcarenite, and an absence of shales. These mounds are surrounded by minor shales and nodular mudstones which support a sparse fauna. On the whole, the Nodular Moundstone lithofacies (BN-1) resembles the Dolomitic Moundstone (BD-1). There is an absence of stromatolites and calcareous algae (except for rare skeletal components coated with Girvanella which may be transported). The density and diversity of archaeocyathids and other organisms is similarly low. The Nodular Mound Unit (BN), therefore, occupies a similar environment as the Dolomite Mound Unit (BD); both deposited in a relatively deep-water (below the photic zone and wave-base), quiet environment.

The locally developed moundstones of the Oolite Bioherm Unit (BB) are internally similar to those of the Red Moundstone lithofacies (BR-1), with abundant calcareous algae, and with a high density and diversity of archaeocyathids and other organisms. Geometrically, however, the Archaeocyathid Bioherm lithofacies (BB-2) forms small, discrete, strongly convex mounds or bioherms which are flanked by 'quiet-water' oolitic calcarenites (see above). The exact depositional environment of this unit can only be speculated because of the peculiar nature of the sediments.

It is suggested, however, that the sediments were deposited in a shallow (within the photic zone), clear, relatively quiet environment with, perhaps, periodic moderate turbulence which formed the irregular coated ooids. This environment is likely to be found in a shallow swale between ooid shoals where a mix of the characteristics of both the Biostrome Facies and the Oolite Sand Facies would occur.

The most characteristic feature of the Grey Moundstone lithofacies (BG-1) is the common occurrence of skeletal (Girvanella) and non-skeletal stromatolites. Small, digitate, non-skeletal stromatolites (Fig. 27) (SH-V type of Logan et al., 1964) occur at Blanc Sablon (Appendix A) where archaeocyathids are rare or absent. Skeletal (Girvanella) stromatolites (Fig. 28) (LLH-C type of Logan et al., 1964) occur at the top of the sequence at L'Anse Amour (Appendix E) and may indicate temporary inter-tidal conditions. For the most part, the Grey Moundstones form low relief, laterally extensive (tens of metres) mounds which contain abundant archaeocyathids and calcareous algae, and which are flanked by skeletal calcarenites consisting of fossils representing a normal, sub-tidal fauna, which show no signs of transport or wear. This would indicate that the Grey Mound Unit was deposited in a predominantly shallow sub-tidal low-energy environment which possibly shallowed periodically into the inter-tidal zone. The lateral contact



Fig.27: Photomicrograph (plane light) of non-skeletal stromatolites (type SH-V) in the Grey Moundstone lithofacies (BG-1) at Blanc Sablon. Note archaeocyathid (Archaeocyathus) at bottom left. Scale bar is 4.5 mm.



Fig.28: Skeletal (Girvanella) stromatolites (type LLH-C) in the Grey Moundstone lithofacies (BG-1) at L'Anse Amour.
Scale is in centimetres.

of the Grey Mound Unit with the spillover part of the oolite shoal at Diversion Reef (Appendix B), and the vertical association of the same two units at Schooner Cove (Appendix G) suggests that the Grey Mound Unit occupied a position behind the active part of the oolite shoal and consequently favoured a protected environment often adjacent to the spillover part of the oolite shoal.

Stratigraphy

Mapping of the major facies indicates that the Oolite Sand Facies was deposited to the north or north-west of the Biostrome Facies and that the contact between the two facies is highly irregular. The map (Fig. 72, in pocket) indicates that salients of the Oolite Sand Facies existed to the west of Forteau and around the bay of L'Anse au Loup, with corresponding recesses to the north of Blanc Sablon and on the Pointe Amour peninsula (with the exception of Schooner Cove).

The distribution of Biostrome Facies units suggests that the maximum development of the deeper-water units (BD and BN) occupy positions further away from the Oolite Sand Facies in a south-east direction while shallow-water units (BR and BG) occur with their maximum development adjacent to Oolite Sand Facies and occupy a position to the north-west of the deeper-water units. This would indicate that the paleoslope was trending towards the south-east and that the Biostrome Facies was deposited seaward of the

Oolite Sand Facies.

Figure 29 illustrates a simplification of the facies and units relationships interpreted from the measured section (Appendices A-H) and uses Fox Cove as the reference section. Deeper-water units (BD and BN) occur only on the Pointe Amour peninsula. In the measured sections at Fox Cove (Appendix F) and L'Anse Amour (Appendix E), the Dolomite Mound Unit (BD) and the Nodular Mound Unit (BN) are separated vertically by a thin bed of Red Moundstone (BR-1). This relationship suggests that the Dolomite Mound and Nodular Mound Units were deeper-water, lateral equivalents of the Red Mound Unit which was deposited seaward, and thickens towards a contact with the Oolite Sand Facies (see Fig. 29). The lower part of the sequence at Fox Cove and L'Anse Amour can be interpreted as a gradual shallowing and then deepening episode. The Dolomite Mound Unit (BD) was initially deposited as a lateral equivalent to, and then overlies, the siltstones and shales of the open-shelf facies. The Dolomite Mound Unit then shallowed sufficiently for the deposition of the calcareous algae-rich Red Mound Unit to be deposited. This event was short-lived, however, as the deeper-water Nodular Mound Unit overlies the Red Mound Unit. The remainder of the sequence consists of shallow-water units; Oolite Bioherm (BB) and Grey Mound (BG) Units. These are separated from the underlying Nodular Mound Unit by a planar erosion surface. The occurrence of these shallow-

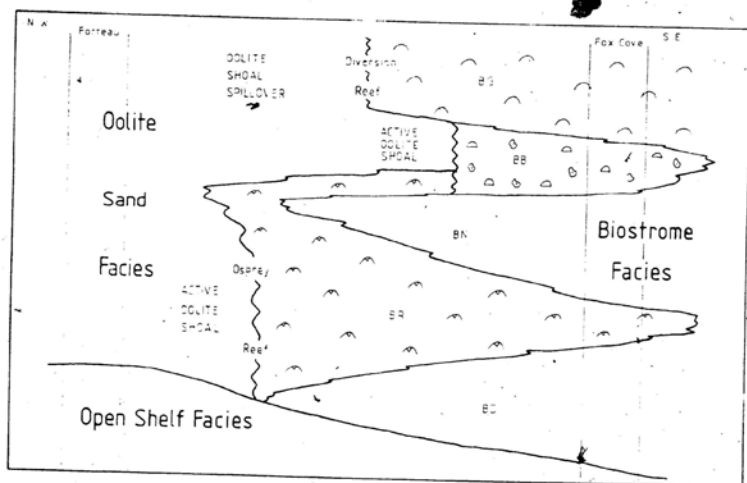


Fig. 29: Schematic synthesis of correlation and facies relationships in the biostrome complex of the Forteau Formation of southern Labrador (not to scale).

water units on the Pointe Amour peninsula may represent a general regression in the area.

The measured section on the north-east side of the Pointe Amour peninsula, at Schooner Cove (Appendix G) is the only sequence where rocks of the Biostrome Facies and Oolite Sand Facies are intercalated. The Dolomite Mound Unit (BD) again overlies the open-shelf Facies but is now overlain itself by skeletal calcarenite which becomes oolitic towards the top. This is probably the lateral equivalent of the Red Mound Unit at Fox Cove. The remainder of the sequence consists of the shallow-water Grey Mound Unit (BG) intercalated with rocks characteristic of the spill-over area of the oolite sand shoal. The corresponding beds at Fox Cove would be the deeper-water Nodular Mound Unit (BN). At the top of section archaeocyathid bioherms are embedded in 'quiet-water' oolites. Most of the succession at Schooner Cove would seem to represent lateral shifting of shallow-water deposits. Such lateral shifting is suggested as the sequence at Fox Cove and L'Anse Amour has the Grey Mound Unit (BG) overlying the Oolite Bioherm Unit (BB) while 3 km to the north-east at Schooner Cove, the reverse is seen.

The inland sections at Osprey Reef (Appendix C) and Diversion Reef (Appendix B) are important as both sections show lateral relationships between the Biostrome Facies and the Oolite Sand Facies and are therefore useful in any

paleogeographic reconstruction. Basically, the section at Osprey Reef shows the thickest development of Red Mound Unit (BR) in lateral contact with cross-bedded oolites representing an active oolite shoal. At Diversion Reef, however, the Grey Mound Unit (BG) is in lateral contact with mixed skeletal-peloid-oolitic-oncolitic calcarenites and dolostones characteristic of the spillover area of an oolite shoal. It is significant that the open-shelf facies thickens considerably in the northern part of the section at Diversion Reef (Fig. 65, Appendix B) indicating that the Oolite Sand Facies as a whole is tapering northwards. This suggests that the oolite shoal itself is merely a lens, replaced to the south by the Biostrome Facies and to the north by the open-shelf facies.

The most north-westerly measured section of the Biostrome Facies to the north of Blanc Sablon (Appendix A) consists entirely of shallow-water deposits overlying siltstones and shales of the open-shelf facies. The sequence consists of two beds of rocks of the Grey Mound Unit (BG) separated by a thin bed of Red Moundstone (BR-1). This sequence may possibly be correlated with the lower part of the sequence at Fox Cove and L'Anse Amour where a thin bed of Red Moundstone separates the deeper-water Dolomite Mound Unit (BD) and the Nodular Mound Unit (BN). These successions may have been caused by a temporary expansion of the oolite sand shoal which caused the adjacent Red Mound Unit

to displace other units. In the case of Fox Cove, the deeper, seaward Units (BD, BN) were replaced; while at Blanc Sablon, the shallow-water Grey Mound Unit was displaced. The lack of rocks representing the Oolite Sand Facies in the area around Blanc Sablon indicates that this area was a recess in the oolite shoal, but the shallow-water nature of the rocks may indicate that they were deposited between two oolite shoals (see Fig. 30).

The sequence at Forteau (Appendix D) and L'Anse au Loup (Appendix H) consists entirely of rocks of the Oolite Sand Facies. Both sequences can be considered to be caused by lateral shifting of facies within the spillover area of the oolite shoal.

Paleogeography

Because of the rapid lateral and vertical changes in lithology experienced in most of the outcrops, any paleogeographical model must be an oversimplification of the true distribution of lithofacies. Bearing in mind that lateral shifting of the shallow-water facies was probably considerable, the model presented (Fig. 30) gives an indication of the facies distribution at one particular time. Stratigraphic evidence suggests that the Biostrome Facies was deposited seaward and south-east of the Oolite Sand Facies. The Oolite Sand Facies consisted of rocks constituting an oolite shoal which can be divided into; an active oolite shoal of cross-bedded oolitic grainstones deposited

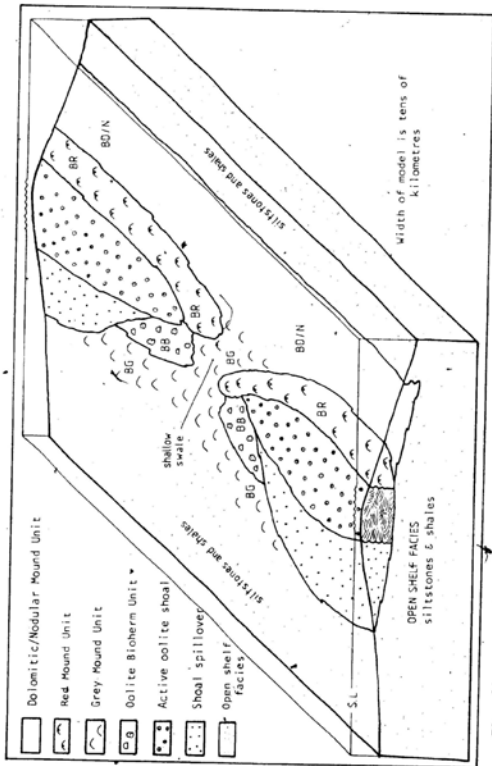


Fig. 30: Schematic model of sedimentation for the biostrome complex of the Forteau Formation of southern Labrador.

in a shallow-water, high-energy environment, and a shoal spillover which was deposited in quieter-water behind the active oolite shoal. Seaward, but in contact with the active oolite shoal, was deposited the Red Mound Unit (BR) in shallow-water, high-energy conditions. In slightly deeper-water (below the shallow photic zone), sediments of the Dolomite Mound Unit (BD) and Nodular Mound Unit (BN) accumulated and probably passed seaward into siltstones and shales (N. James, pers. comm.). Facies mapping indicates that the contact between the Oolite Sand Facies and the Biostrome Facies is highly irregular and suggests that salients, recesses, and possibly breaks occurred between shoals. In some shallow swales between oolite shoals, archaocyathid bioherms accumulated, flanked by 'quiet-water' oolites (Unit BB), with the ooids initially derived from the adjacent shoals. Also on the shallow swales, but generally occupying positions behind the active oolite shoal but in lateral contact with the shoal spillover, the Grey Moundstone Unit (BG) was deposited. The development of extensive stromatolites in this unit suggests that intertidal conditions may have prevailed for some of the time.

Such a facies distribution has broad similarities with recent carbonate environments such as the Trucial Coast of the Persian Gulf (Purser and Godfrey, 1973), and Joulter's Cay, Bahamas (N. James, pers. comm.). In both cases, organic reefs are accumulating seaward of an active oolite shoal

with spillover sediments accumulating behind. The model has a close analogue with the Type 1: Downslope mud accumulation, shelf margin profile of Wilson (1975).

CHAPTER IV: DIAGENESIS

INTRODUCTION

Diagenesis of the various calcarenite lithologies in the Oolite Sand Facies and the flanking calcarenites of the Biostrome Facies are described as one entity because the diagenetic processes which affected them are essentially the same, differing only in minor detail. The various moundstone lithologies of the five assigned units also share a common diagenetic history, again only differing in detail, and so are described as a second entity.

The diagenetic features are also tabulated using the sedimentological division so that comparisons of features can be made within each unit of the Biostrome Facies (Table II).

Several processes have modified the original depositional texture of both the moundstones and the calcarenites; bioerosion, cementation, neomorphism, dolomitization, silicification, pressure solution, and fracturing. Each of the processes is described in turn (where applicable) for both moundstones and calcarenites.

DIAGENESIS OF THE MOUNDSTONE LITHOFACIES

Bioerosion

Evidence of microboring organisms (such as micritic tubules or envelopes) is absent from the moundstone components although macroborings are relatively common in several of the units (Figs. 31 and 32). The macroborings are cylindrical tubes with a diameter of between 0.5 mm

TABLE II. Distribution of diagenetic fabrics within the five units.

LITHOLOGY	Unit	Lithofacies	MICROPOSITION		CEMENTATION			NEOMORPHISM	DOLOMITIZATION			STYLOLITIZATION				Fracturing	
			macroborings	microborings	cloudy fibrous	syntaxial	scalenohedron		ferroan pore-fill	--- of matrix	--- of skeletons	Two stages visible	Irregular, anastomosing	Peaked, low-amplitude	Horse-tail		Nodular-bedding
DOLOMITE	Mound	-	-	A	A	C	A	C	-	-	-	-	-	-	-	-	
MOUND (BD)	Calc.	-	-	A	A	C	A	C	-	-	-	-	-	-	-	-	
RED	Mound	-	C	-	A	A	A	C	R	-	-	-	-	-	-	-	
MOUND (BB)	Calc.	-	-	-	A	A	A	C	R	-	-	-	-	-	-	-	
NODULAR	Mound	-	-	B	C	C	A	C	-	-	-	-	-	-	-	-	
MOUND (BN)	Calc.	-	-	-	C	C	A	R	-	-	-	-	-	-	-	-	
GREY	Mound	-	-	A	A	C	A	C	-	-	-	-	-	-	-	-	
MOUND (BG)	Calc.	-	-	A	A	C	A	C	-	-	-	-	-	-	-	-	
COLLITE	Mound	-	C	A	A	C	A	C	-	-	-	-	-	-	-	-	
BIOHERM (ND)	Calc.	-	C	-	A	C	R	A	-	-	-	-	-	-	-	-	

KEY
 - Absent
 R Rare
 C Common
 A Abundant



Fig.31: Bedding-plane exposure of Dolomitic Moundstone (BD-1) at Fox Cove showing archaeocyathids (Metaldetes) and lime-mud matrix, both penetrated by macroborings (small, dark dots) of the ichnofossil Trypanites. Scale bar is in centimetres.



Fig.32: Photomicrograph (plane light) of archaeocyathid skeleton (left) truncated by the macroboring ichnofossil Trypanites. The vacant boring has since been infilling with skeletal debris (right). Scale bar is 0.45 mm.

and 2 mm, and a length of between 2.5 mm and 3.5 mm. As such these traces can be assigned to the morphogenus Trypanites (Maderfrau). They penetrate archaeocyathid skeletons, clumps of renalcid algae, and the matrix of the rock, which is either cut cleanly, implying lithification, or is pushed aside. The borings have been subsequently filled with either the surrounding matrix, (Fig. 32) or with cloudy, fibrous calcite cement (Fig. 48).

Cementation

The amount of obvious cementation is dependent on the available pore-space and varies greatly between units, in some cases occurring only in intra-skeletal pores of archaeocyathid skeletons.

Two categories of cements are recognised within the moundstone: (1) Rim-cements, which fringe particles; (2) Pore-fill cements, which fill that part of the pore not already occluded by rim-cement.

Rim-cements:

Three different rim-cements can be distinguished within the moundstone: (1) a cloudy fibrous cement (common), (2) a clear scalenohedron cement (common), (3) a micrite cement (rare?).

The cloudy fibrous cement is non-ferroan, but rich in inclusions which give it a brown colour. It occurs as the first cement precipitated in a radial/fibrous habit with sweeping extinction in the following places: in the intra-

skeletal pores of archaeocyathid skeletons (Fig. 34); between, and encrusting bases of pendant coelobitic organisms (Fig. 33); in between heads of small digitate stromatolites; interlayered with internal sediments; lining the floors of cavities. It is also found as blocky, equant crystal rinds within internal sediment in the cavities, around skeletons within the sediment, and lining the floors of cavities. Broken, equant fragments of this cement also occur as part of the internal sediment (Fig. 35).

The clear, scalenohedron calcite cement is also non-ferroan and varies from equant, blocky crystals, to blades, to a fibrous fabric. Correspondingly, the axial ratio varies from 2:1, to an average of 3/4:1, to 8:1. The cement occurs chiefly in skeletons of archaeocyathids where it is either the first cement precipitated (Fig. 36), or is precipitated on top of cloudy fibrous cement (never the reverse), in which case the bases of the individual crystals are in optical continuity with the cement substrate. Pores are often occluded with this cement. It also succeeds cloudy fibrous cement encrusted onto the base of the coelobitic organisms in cavities beneath reticulaminiform archaeocyathids and sometimes occluded with blades of this cement.

A possible micrite cement is precipitated between clumps of pendant renalcid algae in cavities but is probably much more widespread (see discussion).



Fig.33: Photomicrograph (plane light) of a cavity beneath Retilamina. The underside of the skeleton of Retilamina (top) has a thick development of cloudy fibrous cement (C). Both the fracture (Z) and the remaining cavity (F) are occluded by iron-rich pore-fill cement. Note internal sediment forming the floor of the cavity.
Scale bar is 0.45 mm.

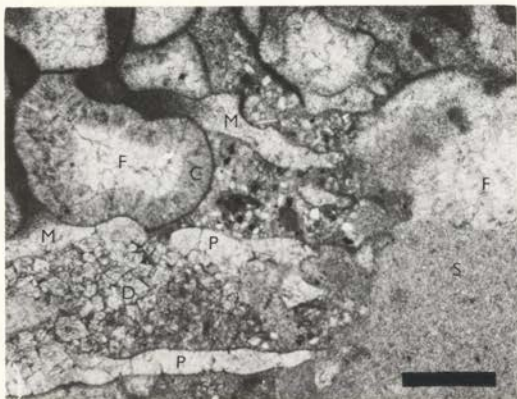


Fig.34: Photomicrograph (plane light) of archaeocyathid skeleton. Original microgranular skeleton (black) has undergone aggrading neomorphism to microspar (M) and pseudospar (P). The central cavity (right) has been partially filled with internal sediment (S). Intra-skeletal pores often have thick rinds of cloudy fibrous cement (C) and are occluded, along with the remaining space in the central cavity by iron-rich pore-fill cement (F). Some of the intra-skeletal sediment has been dolomitized. (D). Scale bar is 0.45 mm.

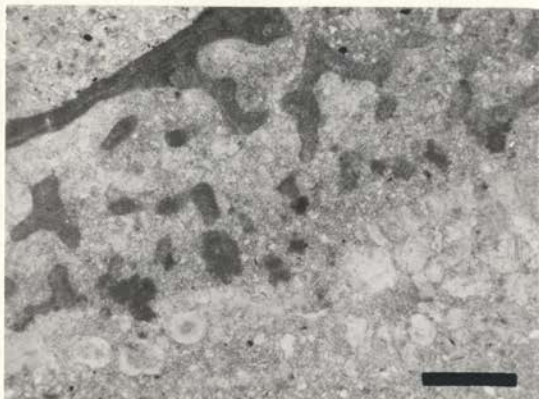


Fig.35: Photomicrograph (plane light) of part of a skeleton of Retilamina (dark area). Beneath Retilamina is a matrix consisting mostly of broken fragments of cloudy blocky cement. Scale bar is 0.45 mm.

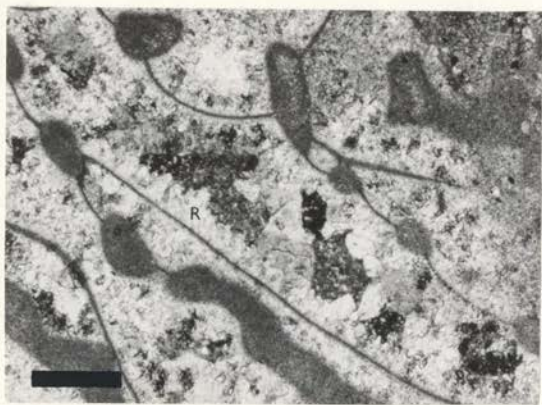


Fig.36: Photomicrograph (cross-polarized light) of an archaeocyathid skeleton. Intra-skeletal porosity is occluded by a rim of clear, iron-poor scalenohedron calcite cement (R) followed by iron-rich pore-fill cement. Scale bar is 0.4 mm.

Pore-fill Cements

Pores within archaeocyathid skeletons, syndepositional cavities, and solution cavities not already occluded by rim-cements, and all fractures are filled with ferroan, pink, often coarsely crystalline calcite (Figs. 33, 34 and 36). Solution of many dragonitic skeletons (brachiopods, hyolithids, etc.) probably occurred coeval with or just prior to the precipitation of this cement as the cavities thus formed are always filled with ferroan cement (rarely the rim-cements).

Neomorphism

Three different neomorphic fabrics are recognised in the moundstone lithofacies: (1) aggrading neomorphism of mud matrix to microspar, (2) aggrading neomorphism of archaeocyathid skeletons to microspar and pseudospar, (3). recrystallization of cement fabrics to pseudospar.

Most of the mud-sized matrix of the moundstones has undergone aggrading neomorphism from micrite to homogeneous microspar (25u). Rare patches of relict micrite exist, normally between clumps of coelobite organisms in cavities.

The microgranular (calcite) skeleton of archaeocyathids has commonly undergone aggrading neomorphism from its original form to microspar with relict patches of the microgranular fabric enclosed within it. The microspar has then been aggraded to clear crystals of ferroan pseudospar, which strongly resembles a pore-fill cement, but is regarded as

neomorphic as the complete transition from microgranular calcite to pseudospar is often observed (Fig. 37).

The recrystallization of the radial cloudy fibrous calcite cement to a blocky, cloudy pseudospar fabric rarely occurs.

Dolomitization

The most extensive dolomitic fabrics form the large dolomite pods (Fig. 15) in the Dolomite Moundstone lithofacies (BD-1). The dolomite rhombs are euhedral and form a homogeneous, idiotopic texture. Individual crystals are iron-rich, with an average size of 25u. Small isolated patches of skeletal calcarenite and archaeocyathids are enclosed by the dolomite, and isolated rhombs occur throughout the calcarenite.

Partial, patchy dolomitization is common throughout the moundstone. The dolomite is again homogeneous, euhedral, idiotopic, and iron-rich with crystals averaging between 30-60u in size but ranging from 25-200u. A later, coarser dolomite occurs rarely with rhombs averaging 185-200u. Both stages post-date fracturing of the rock, so occur relatively late in the diagenetic history.

Although pervasive, the dolomitization often leaves echinoderm plates undolomitized except for corroded margins, but sometimes preferentially selects archaeocyathid skeletons, particularly those already neomorphosed to pseudospar.

Dolomite rhombs also occur as stylolite reactates.

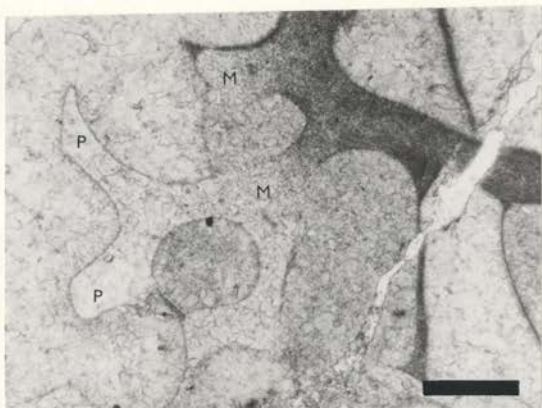


Fig.37: Photomicrograph (plane light) illustrating the aggrading neomorphism of an archaeocyathid skeleton. The original microgranular skeleton (dark area) has been aggraded to microspar (M) and pseudospar (P). Scale bar is 0.3 mm.

Stylolitization

Abundant stylolites occur as two types; (1). Irregular, anastomosing swarms of non-sutured seams (Wanless, in press), where the seams are gently undulating, often divide and rejoin, and are associated with thick stylecumulates, (2). Horse-tail stylolites, defined as "wispy, subparallel microstylolites that converge into a single residual seam" (Mossop, 1972).

Within the units, stylolites vary in density from absent to abundant, and when abundant give a stylonodular appearance to the rock.

Quartz silt, clay minerals, and heavy minerals generally occur as stylocumulates, and dolomite rhombs grow as styloreactates.

Fracturing

Fractures vary in density from absent to common, and although they can be up to 3 mm wide, are generally much smaller. Fracturing occurred after the precipitation of rim-cement and was probably coeval with the precipitation of the equant ferroan pore-fill cement which always occludes the fractures (Fig. 33).

DIAGENESIS OF THE CALCARENITES

Bioerosion

Evidence of the activity of microborers is indicated by the presence of micritic envelopes (Bathurst, 1966) around components and by the rarer occurrence of totally micritized peloids which, because of their size and shape, are not

fecal pellets.

In this study, microborings are commonly found in echinoderm plates, Salterella cones, hyolithids, and ooids in the skeletal, oolitic, mixed oolitic, and oncolitic grainstones of the Oolite Sand Facies and are restricted to the Oolitic Calcarenites (BB-1) in the Biostrome Facies. In all situations, microborings are preserved as micritic tubules are well-preserved enough to be attributed to the blue-green algae Girvanella (Fig. 50).

Micrite in the envelope has often been dolomitized and has rarely been neomorphosed to microspar.

Cementation

Two categories of cement occur in the calcarenites:

- (1) Rim-cements which fringe the particles, and (2) Pore-fill cements of precipitated calcite which occlude that part of the pore not occluded by the rim-cements.

Rim-cements

A total of 5 different, but sometimes gradational, calcite rim-cements can be distinguished within the calcarenites. Syntaxial overgrowths and bladed scalenohedra are common while radial-fibrous, blocky scalenohedra, and micrite are rarer.

Syntaxial cements occur most commonly on, and within, echinoderm plates, either filling the pores in the plates or enlarging their margins by syntaxial overgrowth (Fig. 50).

This cement occurs in all lithologies containing echinoderm plates but is not seen on plates possessing micritic envelopes which apparently inhibit any syntaxial overgrowth (Fig. 50). A second type of syntaxial cement is precipitated as non-ferroan bladed scalenohedra between 75u and 300u long with an axial ratio of 5:1, precipitated in optical continuity on to concave lower surfaces of trilobites in mixed peloid and mixed oncolitic grainstones of the Oolite Sand Facies (Fig. 38). The origin of this fabric as cement is not unequivocal, however, and a neomorphic origin cannot be ruled out (see below).

A clear, non-ferroan scalenohedron cement of bladed habit with pyramidal terminations (often iron-rich) to the individual crystals which range between 200u and 500u long with an axial ratio of 3 to 5:1, is often nucleated as the first cement. This cement is found on ooids and peloids in the skeletal grainstones; beneath trilobites in the mixed oolitic grainstones; on peloids and ooids in the oolitic grainstones. It also occurs on trilobites, brachiopods, archaeocyathids, and ooids in the calcarenites of the Biostrome Facies.

The less common radial-fibrous cement occurs as needles or elongated blades, 30-40u long with an axial ratio of 7:1 on ooids in the oolitic calcarenites of both facies.

Blocky spar consists of sub-equant crystals (axial ratio less than 2:1) between 30u and 100u in size. It occurs on

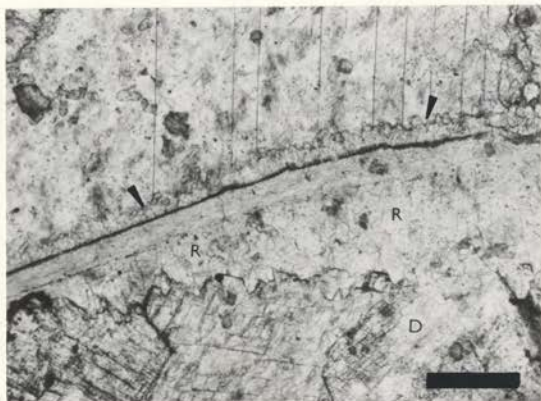


Fig.38: Photomicrograph (plane light) of a trilobite carapace illustrating gravitational cement. On top of the carapace a thin rim of clear, blocky, calcite cement has been precipitated (arrowed) while on the undersurface, a much thicker rim of clear, bladed, calcite cement (R) occurs. Iron-rich, pore-fill cement occludes the pore-space above the trilobite while large, iron-rich dolomite rhombs (D) occur beneath the bladed calcite cement. Scale bar is 0.15 mm.

the top surface of trilobite carapaces which have bladed cements on concave lower surfaces (Fig. 38), and occurs as 100u crystals on micritized peloids and ooids in the mixed oncolitic grainstones. It is well displayed in the intraclast grainstone forming a rim of 40u crystals around algal intraclasts which are not in direct contact with microspar.

A presumed micrite cement occurs within the rare composite grains in the oolitic grainstones and mixed oncolitic grainstones of the Oolite Sand Facies.

Pore-fill cements

The same ferroan, coarsely crystalline pore-fill cement that occurs in the moundstones also occurs in most of the calcarenite lithotypes. It is absent, however, from lithologies consisting entirely of echinoderm plates but contributes up to 40% of the rock volume in the intraclast grainstone of the Oolite Sand Facies (Fig. 22).

Neomorphism

Neomorphic fabrics occur throughout the calcarenites in varying amounts and are represented by aggrading neomorphism of micrite mud to microspar and formation of microspar and pseudospar in archaeocyathids. Both of these fabrics are identical to those described from the moundstones. Other neomorphic fabrics include the formation of pseudospar and pseudo-radial microspar in ooids; symaxial neomorphic rims and blades on echinoderm plates and trilobites, respectively; and a complete recrystallization fabric.

Ooids in the oolitic calcarenites are neomorphosed in one of two ways. Commonly the radial-concentric structure of ooids has been aggraded to a single crystal of clear, ferroan pseudospar with a "ghost" relict nucleus of an echinoderm fragment (non-ferroan). The margins of the ooids are nearly always composed of a dark layer, possibly organic, of varying thickness (Fig.39). Rarely, and only observed in the oolite calcarenites of the Biostrome Facies, the radial-concentric structure of the ooids has been neomorphosed to microspar which displays a pseudo-radial fabric due to the elongation of some of the crystals normal to the surface of the nucleus of the ooid.

Some of the syntaxial overgrowths observed on echinoderm plates and trilobite carapaces may be of neomorphic origin as they embay the mud (micro-spar) matrix which is probably of primary origin as the texture of the sediment in some places is a wackestone, implying that the original components had to be mud-supported. In one instance, bladed syntaxial crystals develop on the underside of a two walled skeleton and replace the interior of the shell as well as the lower skeletal wall and subsequently embay echinoderm plates. This may suggest a neomorphic origin of some of the bladed cement fabrics described above.

A total recrystallization fabric occurs in some of the oolitic and mixed oolitic grainstones close to the contact with the Biostrome Facies at Osprey Reef. The fabric dev-

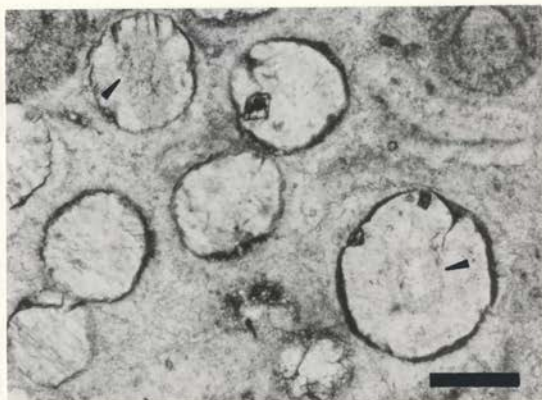


Fig.39: Photomicrograph (plane light) of neomorphosed ooids. The original radial-concentric structure of the ooids has been replaced by a single crystal of iron-rich pseudospar. Note the relict "ghost" nucleus (arrowed) in some of the ooids, and the black rim on all of the ooids. Scale bar is 0.3 mm.

eloped here is a mosaic of dolomitized ooids (where dolomite rhombs have overgrown the margin of the ooid), and medium to finely crystalline pseudospar.

Dolomitization

Dolomitization is prevalent in the calcarenites in a number of forms including selective dolomitization of previously neomorphosed archaeocyathid skeletons and of individual ooids, a dolomite mottling fabric, and total dolomitization.

Archaeocyathid skeletons (in the Biostrome Facies calcarenites), that have previously been neomorphosed have often undergone selective dolomitization with large (250u) ferroan dolomite rhombs replacing the pseudospar.

Dolomitized ooids are common in both facies. Three basic types of dolomitized ooids occur in the Oolite Sand Facies ooids. The first type occurs when the ooid is replaced by a single crystal of ferroan dolomite of average size 300u which is generally confined to the original boundaries of the ooid but occasionally transgresses that boundary (Fig. 40). The second type occurs when the ooid is replaced by several smaller (60u) crystals of ferroan dolomite (Fig. 41). This type of dolomitization also occurs in the Biostrome Facies ooids. The third type consists of a mosaic of numerous, very small (20-25u) rhombs of ferroan dolomite. In the latter two cases, the nucleus is rarely preserved as a corroded echinoderm plate.

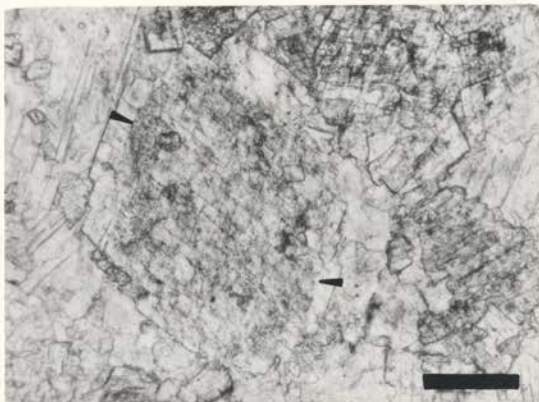


Fig.40: Photomicrograph (plane light) of dolomitized ooids. The original ooid can be seen as a vague, dusty relict (arrowed) in the centre of the large dolomite rhomb. The ooid has been replaced by the single rhomb of dolomite which continued to grow beyond the margins of the ooid. Scale bar is 0.15 mm.

A dolomite mottling texture can often be attributed to preferential dolomitization of areas of bioturbation or burrowing (Fig. 42), but in other cases this pervasive texture is not obviously related to any particular factor. Distinct dolomitized burrows often have ill-defined margins which extend into the encompassing sediment. The dolomite forms as iron-rich equant rhombs in an idiotopic texture although individual rhombs are often smaller at the centre of the burrows (15-25u) than at the margins (30-74u). Similar size ranges and textures are seen in the pervasive dolomite mottles. In both cases, isolated skeletal components (echinoderm plates and trilobites) are surrounded by dolomite rhombs, but have corroded margins. The mottling is seen in all lithotypes except the oolitic, mixed oolitic, and intraclast grainstones. Two stages of dolomitization can be distinguished in the calcarenites which flank Grey Moundstone (BG-1). Both stages consist of euhedral, idiotopic, iron-rich rhombs, differentiated by their crystal size; the first stage averaging 150u, and the later stage 600u which commonly occurs in original sydepositional cavities.

Dolostones and dolomitic siltstones are common within the Oolite Sand Facies. The dolostones can be divided into fabrics which retain their original components and textures as "ghost" relics, and fabrics where no original components or textures are preserved.

The original texture is best displayed by dolomitized oncolitic grainstones at the top of the section to the west

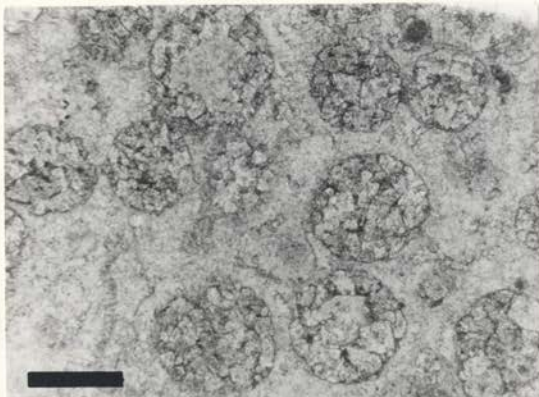


Fig.41: Photomicrograph (plane light) of dolomitized ooids. The original ooids have been replaced by several rhombs of iron-rich dolomite. Note the rim-cements around the ooid have remained unaltered. Scale bar is 0.45 mm.

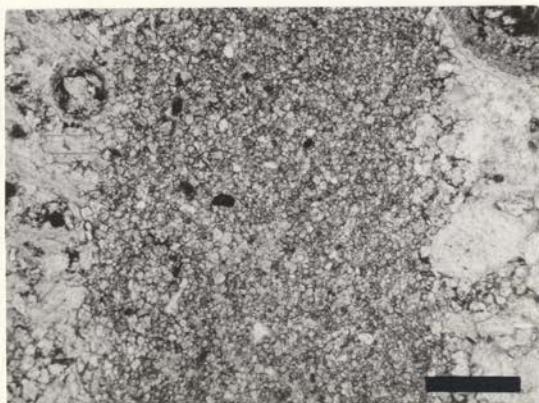


Fig.42: Photomicrograph (plane light) illustrating a burrow in skeletal calcarenite of the Oolite Sand Facies. The burrow (centre) has been selectively dolomitized while the matrix remains unaltered. Scale bar is 0.45 mm.

of Forteau. The only grains left undolomitized are echinoderm plates, but even they have corroded margins. The dolomite 'matrix' consists of equant idiotopic (75-250u), Fe-rich rhombs. Components still identifiable in the 'matrix' include Salterella, whose cones have been replaced by clear, non ferroan rhombs (50-100u) with the matrix inside the conch consisting of smaller (25-75u), dusty rhombs. Oncolites now consist of a nucleus of finely crystalline, cloudy dolomite (50-75u), surrounded by clear, coarser, hypidiotopic dolomite rhombs (50-200u), and rimmed with medium size (50-125u), cloudy rhombs. A later stage ferroan, coarse (up to 2 mm) dolomite with strained crystals (curved twins and undulose extinction), partly replaces the earlier dolomite texture of some of the oncolites.

Dolostones with no preserved textures consist of euhedral rhombs in an idiotopic texture and may contain up to 50% quartz silt. Textures with both ferroan dolomite rhombs, surrounded by a mosaic of coarser crystals, probably represent original burrows.

Silicification

Silicification is uncommon, late stage and restricted to the Oolite Sand Facies where chert replaces internal matrix in Salterella cones and forms a fabric consisting of 30% dolomite rhombs and 70% chert. Very rarely, euhedral dolomite rhombs have been totally replaced by quartz.

Pressure solution

Pressure solution at grain contacts due to compaction is rare and is only seen in dolomitic siltstones of the Oolite Sand Facies where quartz grains are seen to embay one another. Stylolites are common in all of the calcarenites and two types can be distinguished: (1) Irregular, non-sutured seams (Wanless, in press). The seams are gently undulating, often divide and rejoin, and are associated with thick (up to 1 mm) stylocumulates consisting predominantly of quartz, clay minerals, and opaque minerals. (2) Clean, sutured seams (Wanless, in press). The seams are jagged of low amplitude and with thin stylocumulates. They trend mainly parallel to bedding, but are rarely normal to the bedding.

It is apparent by the concentration of quartz grains in the stylocumulate as compared to the rest of the sediment, and by the visible dissolution, in some cases of 90% of some ooids, that dissolution was considerable.

Stylolifization appears to have occurred at several times during the history of the rock as it predates pervasive dolomitization in the skeletal grainstones (common), post-dates dolomitization of dolostones (rare) as part of the rhombs have been dissolved, and post-dates dolomitization of the ooids in the mixed oolitic grainstone (rare).

Fracturing

Fractures are rare and consist of thin cracks (less than 65u). The event occurred after the precipitation of rim-cements, and was probably coeval with the precipitation of equant ferroan pore-fill cement which always occludes the fractures.

DIAGENESIS OF OIDS

The diagenetic sequence of preservation and replacement of ooids is summarized diagrammatically (Fig. 43). The order of replacement is always the same; the initial radial-concentric fabric consisting of a nucleus (echinoderm fragment) surrounded by a radiating cortex of calcite prisms interrupted in the outer two-thirds of the ooid by concentric lamellae of dark, possibly organic, material, is neomorphosed to a single, clear, ferroan pseudospar crystal (Fig. 39). Micritization (micrite envelope or peloid) sometimes precedes neomorphism. Partially neomorphosed ooids are only rarely encountered, possibly suggesting an efficient mechanism of replacement. Both neomorphosed ooids and radial-concentric ooids that did not undergo neomorphism were dolomitized in one of several ways. Commonly the ooid is replaced by a single, ferroan dolomite rhomb which occasionally overgrows the margin of the ooid (Fig. 40). Several smaller (25-60u) ferroan dolomite rhombs often replace the pre-existing fabric (Fig. 41) and sometimes overgrow the margin of the ooid. The

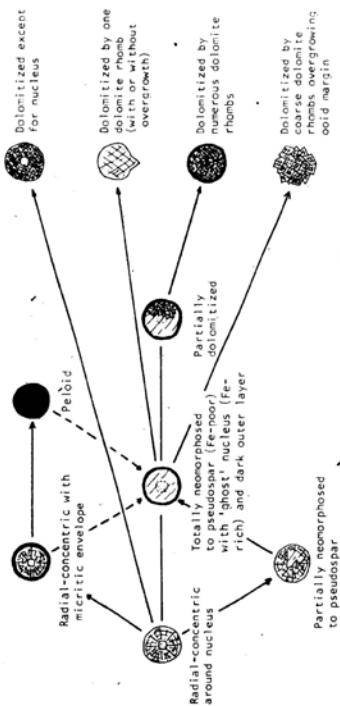


Fig. 43: Sketch illustrating the diagenesis of ooids.

nucleus' (echinoderm fragment) is rarely preserved in dolomitized ooids and indicates that some of the radial-concentric ooids were dolomitized without first undergoing neomorphism. In most cases, both neomorphosed and dolomitized ooids are surrounded by a concentric, marginal layer of dark possibly organic-rich material (Fig.39). In all cases, rim-cements precipitated onto the ooids remain unaltered unless the margin of the ooid (and the cement) is overgrown by dolomite rhombs.

DISCUSSION

Bioerosion

Bioerosion, in the form of micro-and macroborings plays a significant role in the development of modern day reefs (James, 1970; Bromley, 1978) by weakening skeletal frameworks and producing sediment. Although the activity of both microborers (represented by tubules, micritic envelopes and peloids) and macroborers (represented by borings attributed to the morphogenus Trypanites), is present, their contribution to the overall fabric of the rock is minimal. The importance of the macroborer Trypanites lies in the fact that it is the oldest macroborer yet recorded (James, Kobluk and Pemberton, 1977) and thus has important implications in the evolution of macroboring organisms (Kobluk, James and Pemberton, 1978).

Cementation

Rim-cements

The several types of rim-cements, including micrite, were probably precipitated in a number of diagenetic environments. With the absence of characteristic criteria however, it is often difficult to pin-point the precise location of precipitation of some of the cements, particularly as it is unwise to rely on the cement fabric alone which is more often than not seen to be precipitated in more than one environment (Schroeder, 1973).

The cloudy fibrous cement is interpreted as being submarine in origin for a number of reasons. It is facies specific, occurring only in the moundstones and never in the flanking calcarenites. Facies specificity of cements is known only in submarine environments (James, Ginsburg, Marszalek and Choquette, 1976). Where present it is always the first rim-cement precipitated but may be overlain by others. The cement is interlayered with internal sediment inside cavities and loose, detached blocks of cement occur within sediment, implying that cementation and sedimentation were contemporary. The fabric of the cement is fibrous and inclusion-rich, a common characteristic of recent synsedimentary cements (Bricker, 1971; p. 47). Lastly the cloudy fibrous cement is penetrated by borings whose vacant cylinders are also often occluded with this cement. The penetration of cements by borings

is often used to denote a submarine origin for cement (e.g. Purser, 1969; James and Kobluk, 1978).

A volumetrically important rim-cement is the syntaxial overgrowth on echinoderm plates. This type of cement has been interpreted in other rocks to be of submarine origin (Purser, 1969), of vadose origin (Talbot, 1971), or phreatic origin (Evamy and Shearman, 1965). The non-ferroan nature of this cement in the rocks under study, which have a high iron content (James and Kobluk, 1978) suggests that iron was in a ferric state, above the water table and in contact with air so was unable to be accommodated into the crystal lattice. The syntaxial cements were, therefore probably precipitated from meteoric waters in the vadose zone (cf. Talbot, 1971).

The vadose diagenetic environment was probably the site of a considerable amount of rim-cementation. The blocky and bladed spar cements are interpreted as being of vadose origin as they show geostrophic growth (Fig. 38) with bladed spar often occurring on the underside of shells growing downwards and achieving considerable length, while on the upper surface of the shell, blocky, equant spar of more restricted dimensions has been precipitated. This denotes that the cement was precipitated under the influence of gravity from meteoric waters percolating down through the rock. This type of geostrophic cementation is well documented from subaerial environments (e.g. Taylor and Illing, 1969; Purser, 1969;

Muller, 1971) and is often known as gravitational or stalactitic cement. The non-ferroan nature of these cements also infers a subaerial, vadose environment (Talbot, 1971).

The most difficult rim-cement to interpret is the radial-fibrous/bladed fabric occurring on the ooids in both Oolite Sand Facies and the Biostrome Facies. The ooids are rimmed with a fibrous/bladed cement around the entire circumference of the grain, but the cement thickens away from grain contacts and into the pore space. This implies that the initial pore space was entirely filled with pore-water, a situation found in saturated conditions below the water table, either in a submarine or phreatic environment. Pore-waters in the vadose environment are often restricted to grain contacts and produce meniscus cements (Dunham, 1971). The presence of several laterally restricted erosion surfaces in the Oolitic Calcarenes (BB-1) of the Biostrome facies suggests that early lithification of the sediment occurred and may indicate a submarine origin. The cement fabric is also similar to cements previously attributed to submarine environments (Purser, 1969). Circumstantial evidence suggests therefore that the radial fibrous cements around the ooids may be syngenetic and therefore submarine.

A syngenetic (submarine) origin for a micrite cement is indicated for both the moundstones and inter-particle between grains in the 'grapestone' of the Oolite

Sand Facies. Recent grapestones are reported to be cemented by the precipitation of aragonitic micrite (Bathurst, 1971) and probably occurred in the rocks under study. Early lithification of the moundstones is indicated as the mud matrix (now microspar) is cut clearly by macroborings (Trypanites) suggesting that a micrite cement may have been involved. Micrite cements of submarine origin are commonly recorded from Recent environments (Schroeder, 1973; James et al., 1976).

Pore-fill cement

Pore-fill cements of anhedral coarse pink calcite are interpreted as being deposited in the phreatic diagenetic environment. The cements are invariably ferroan implying that the iron was in a ferrous (reducing) state and able to be incorporated into the crystal lattice. This process occurs out of contact with air, below the water table in the phreatic zone (Evamy, 1969; Talbot, 1971; Bathurst, 1971). The large size of crystals relative to the vadose cements is also indicative of the phreatic zone (Land, 1970; Thorstenson, Mackenzie and Ristvet, 1972; Steinen, 1974).

Neomorphism.

The most common type of neomorphism is aggrading neomorphism of micrite to microspar, often reported from ancient rocks (Folk, 1975) and probably occurring in the phreatic environment (Bathurst, 1971) although there is

no direct evidence for this.

All of the examples of pseudospar in the rocks under study are ferroan which infers that the growth of pseudospar at the expense of the ooid fabric or archaeocyathid skeleton was influenced by the pore-water, almost certainly in the phreatic environment. This implies that the growth of neomorphic spar occurred in a wet environment, probably by the migration of a solution film in a system of pores between two crystal lattices (Bathurst, 1971) and incorporated iron in a ferrous state into the growing lattice from the pore fluid.

It is difficult to ascertain whether the transitional fabric, micrite-microspar-pseudospar observed in the archaeocyathid skeletons is the result of one or two events of neomorphism. But if one considers that the growth of neomorphic spar occurs by migration of a solution film between two crystal lattices with one crystal growing at the expense of another (wet boundary migration of Bathurst, 1971), then there must have been two stages of growth. The first stage, or "pulse" of wet boundary migration converted part of the micrite skeleton to microspar and then stopped; the second stage or "pulse" then converted the microspar to clear, ferroan pseudospar and then either stopped, or continued. If the process continued past the terminating point of the first pulse, then the micrite skeleton was not converted to pseudospar, but to microspar thus making the effects

of 2 pulses indistinguishable (Fig.44), Although it can be argued that the extent of pseudospar is equal to the extent of neomorphism in the first pulse as pseudospar only replaces microspar.

Aggrading neomorphism of some ooids also presents interesting problems. Very often the 'ghost' nucleus of the ooid, almost always an echinoderm plate, is present and is always non-ferroan whereas the encircling crystal of pseudospar is always of ferroan calcite though both nucleus and pseudospar are optically a single crystal. Unaltered ooids seen in thin-section generally consist of 2 to 3 concentric layers of what appears to be organic-rich material. What has happened therefore to those layers during the growth of pseudospar? Although little is known on the subject, it is generally believed that organic material inhibits the precipitation of calcite (Bathurst, 1971). Petrographic observations suggest that the organic material has been pushed to the margin of the ooid during the growth of pseudospar, as there is an unusually thick rind of dark material in that position (fig.35). The optical relationship between the nucleus and the pseudospar suggests that the pseudospar is a neomorphic syntaxial rim of an echinoderm plate. But if this is so, why is the margin of the ooid never breached by pseudospar? Such detailed problems are beyond the scope of this study.

STAGE 1: INITIAL MICROGRANULAR SKELETON



STAGE 2: FIRST PULSE OF WET BOUNDARY MIGRATION
Part of the original microgranular skeleton is aggraded to microspar (4-40 μ).



STAGE 3: SECOND PULSE OF WET BOUNDARY MIGRATION
More of the original microgranular skeleton is aggraded to microspar. The microspar formed in stage 2 is aggraded to pseudospar.



Fig. 44: Sketch illustrating aggrading neomorphism of archaeocyathid skeletons (based on fig. 38).

Dolomitization

The selective dolomitization of certain structures is a prime problem of the rocks under study. This phenomena, whether it is dolomite mottling, or the selective dolomitization of sedimentary structures is well documented in the rock record (Beales, 1953; Shinn, 1968; Kendall, 1977; Morrow, 1978), and is usually explained by sediment heterogeneity which allows dolomitic brines to selectively pass through the rock. This was probably the case with the rocks under study. The two features which are most often selectively dolomitized are the dolomite pods which occur in the Dolomitic Moundstone lithofacies (BD-I) and bioturbation (including burrowing) features common in the Oolite Sand Facies.

In the case of the dolomite pods, the sediment heterogeneity may have been caused by the early lithification of the moundstone relative to the pods. Evidence for synsedimentary cementation of the moundstone has already been presented (submarine cements and micrite cut by borings) and although the nature of the original sediment of the dolomite pods has been obliterated, several structures are still preserved. For example, on some weathered surfaces, horizontal laminations and trace fossils (burrows, track, and trails) are seen (Fig. 16). Neither laminations nor trace fossils occur within the moundstone suggesting that the two adjacent deposits

differed greatly in their original form, the moundstones being lithified to some degree, and the pods remaining as soft sediment. This would provide the necessary heterogeneity for the dolomitic brines to preferentially select the more permeable pods (cf. Kendall, 1977).

The dolomite mottling caused by the preferential dolomitization of burrows and bioturbation fabrics has been described several times from the rock record (Kendall, 1977; Morrow, 1978). This fabric occurs in the bioturbated sediments of the Oolite Sand Facies in the rocks under study. Heterogeneity in the sediment was established possibly because the bioturbated sediment was more porous than the matrix and was therefore selectively dolomitized (Morrow, 1978). As the matrix is a grainstone, however, the reverse would probably have been true as grainstones have very high initial porosity (Dunham, 1962). The alternative is that the matrix (grainstone) underwent early lithification (vadose) relative to the bioturbated sediment, remained uncemented and hence more permeable and susceptible to dolomitization by percolating brines (cf. Kendall, 1977).

If the mechanism of selective dolomitization was by the percolation of brines through a permeable versus non-permeable sediment then dolomitization must have been relatively early, before lithification of the sediment. Petrographic evidence suggests, however, that dolomitization, was diagenetically late, i.e. post phreatic (last stage)

cementation and stylolitization; evidence contrary to the hypotheses. Field evidence on the other hand indicates that the dolomite pods were lithified prior to the intense stylolitization that affected the moundstones. Stylolites do not pass through the pods but give the impression that the moundstone is "wrapped around" the pods (Fig. 15). This implies two things: (1). That the pods were lithified relatively early (pre-stylolitization); (2). The pods did not consist of calcite when they were lithified otherwise the stylolites would not have avoided them. A logical explanation therefore is that the pods were lithified by early dolomitization, the fabrics of which have since been masked by a later event of dolomitization. The early dolomitization may have acted as a centre of nucleation for the later dolomitization (incorporating several stages) which was however, more widespread, involving dolomitization of phreatic cements, pseudospar and occasionally other sediments.

The timing and environment of early dolomitization is not clear as the fabrics have been masked by later dolomitization. The dolomite was probably not formed in the submarine environment as this generally requires salinities between 4 and 6 times that of normal seawater and is usually associated with the elimination of calcium sulphate (Liebermann, 1967). There is no evidence of hypersaline conditions existing in the Forteau

Formation as the organisms are considered stenohaline (Heckel, 1972) and no evaporite deposits are present. The most likely environment for the early dolomitization is at the interface between meteoric phreatic water and marine phreatic water (zone of mixing), where carbon dioxide-rich meteoric waters infiltrate the sediments (selectively) and mix with sea-water and precipitate dolomite, (Land, 1973a,b).

Stylolitization and Fracturing

Two types of stylolites are seen to be facies specific in the biostrome complex. Clean, sutured seams, generally of low amplitude and often laterally persistent are restricted to the calcarenites. In the moundstones stylolites occur as anastomosing swarms of fine non-sutured seams, grading into horse-tail stylolites. The reason for the difference in stylolite type is probably related to the percentage of insolubles present in each lithology. The relatively high silt and clay content in the moundstones concentrates at stylolite seams where it eventually inhibits further solution by 'clogging up' the seam. This initiates solution in another, adjacent area, resulting in a mosaic of anastomosing solution seams which eventually leads to a nodular appearance in the rock. Coarse skeletal material, in this case archaeocyathids, are known to provide structural resistance to stylolitization and may define the position and size of a nodule (Wapless, in press). This is certainly the case in moundstones where stylolites are

often seen to abut against archaeocyathid skeletons.

The calcarenites contain much less insoluble material and as a result solution is not inhibited along any seam allowing the development of clean sutured seams which are well-spaced and occur in much fewer numbers, than the non-sutured seams of the moundstones. However, where the silt and clay fraction is high in the calcarenites, anastomosing, non-sutured seams do occur.

Stylolitization co-occurs with fracturing and the precipitation of iron-rich pore-fill cement although it is evident that either stylolitization or fracturing is the dominant form of pressure release in any one thin-section studied. The abundant stylolitization is an obvious source of the iron-rich pore-fill cement in the phreatic environment.

Summary of Diagenetic History

Table III summarizes the diagenetic history and relates petrographic fabrics to diagenetic processes and environment. Fabrics are interpreted to have formed in submarine, mixed meteoric phreatic-marine phreatic, vadose phreatic, and a late unspecified diagenetic environment.

Submarine diagenesis was restricted to bioerosion (by both micro-organisms and metazoans) and facies specific cementation, lithifying the moundstones and cementing the ooid grainstones.

As the sediments were buried, selective dolomitization and lithification of pods and bioturbation

TABLE III. Summary of diagenetic processes and fabrics.

ENVIRONMENT	PROCESS	FABRIC
SUBMARINE	Bioerosion	macroborings (<u>Trypanites</u>) microtubular (<u>Girvanella</u>) micritic envelopes peloids
	Cementation	micrite cloudy-fibrous cement radial fibrous cement on ooids
ZONE OF MIXING (meteoric phreatic- marine phreatic)	Dolomitization	selective dolomitization
VADOSE	Dissolution	rare solution cavities rare leaching of aragonite shells
	Cementation	syntaxial cement on echinoderm plates blocky spar cement bladed spar cement
PHREATIC	Fracturing	small fractures
	Dissolution	rare cavities common leaching of arag- onite shells
	Stylolitization	stylolites nodular bedding
	Cementation	ferroan pore-fill cement
	Neomorphism	microspar pseudospar
UNSPECIFIED (Late diagen- etic)	Dolomitization	dolomite
	Silicification	rare silica replacement
	Stylolitization	rare stylolites

fabrics occurred in the zone of mixing between meteoric phreatic and marine phreatic waters (Land, 1973 a, b). Burial was probably not great as the sediments were then uplifted into the vadose diagenetic environment where rim-cementation occurred affecting all lithologies. Minor dissolution must have occurred at this time as rare small solution cavities and leached aragonitic shells are rimmed with vadose cements. Exposure to the vadose environment must have been for a considerable time as the cements are quite well-developed in an environment where diagenetic processes are notoriously slow (Land, 1970; Steinen, 1974).

Burial into the phreatic environment caused extensive fracturing, dissolution of aragonitic shells, stylolitization, pore-fill cementation utilizing iron-rich solutions released by stylolites, and neomorphism. Burial was probably considerable to cause such extensive pressure solution and fracturing from overburden.

A late, undated diagenetic event caused further dolomitization, minor replacement by silica, and rare stylolitization.

CHAPTER V: PALEOECOLOGY OF THE BIOSTROME FACIES

INTRODUCTION

This is a qualitative review of the distribution of organisms in the mounds and calcarenites, the roles that these organisms played, and the structure of each organism association with regard to trophic grouping.

Data was obtained from field observations and supplemented by thin-section study. Where outcrop was sufficient, metre square quadrants were marked off and the organisms counted, with particular attention being paid to the morphology, size, and preservation of archaeocyathids in the moundstone. Where outcrop was restricted, areas of varying sizes were counted and the area noted.

Information regarding the density of organisms in the mounds is biased because of the intense stylolitization that has masked the original disposition of the skeletons and has caused severe vertical dislocations of individual skeletons relative to each other. It is noticeable that the mud matrix was dissolved more than archaeocyathid skeletons as the stylolites often bend around skeletons or abut against them. In view of the stylolitization problem, the density of the distribution of organisms is considered a maximum figure and was probably less at the time of deposition.

The autecology (Ager, 1963) of the main organisms

which occur in the mounds and calcarenites of the Biostrome Facies is described and discussed. The synecology (Ager, 1963) describes three distinct faunal assemblages: the mound assemblage, the calcarenite assemblage, and a coelobitic (cavity dwelling) assemblage which occurs in some of the mound lithofacies. The mound and calcarenite assemblages are considered to be original separate "communities" because; (1) There is little evidence of transportation of skeletal elements in either lithofacies, a great proportion of the mound organisms are preserved in situ, and skeletal elements of the calcarenites are mostly unbroken, although often disarticulated (which is due to spontaneous disintegration upon death). (2) The separation of organisms between the mounds and calcarenites is too clear to be fortuitous and must reflect the original distribution of the organisms.

The relative distribution of the organisms in the various moundstone and calcarenite lithofacies is tabulated in Table IV and is discussed later.

AUTECOLOGY

Archaeocyathids

Archaeocyathids are the principal skeletal components in the Biostrome Facies. Very little is known of their paleoecology (Hill, 1972), but by counting, measuring, and noting morphologies within the five lithofacies, it

TABLE IV. Distribution and relative abundance of organisms
in the five units.

	DOLOMITE MOUND		RED MOUND		NODULAR MOUND		GREY MOUND		OOLITE BIOHERM		
	Mound	Calc.	Mound	Calc.	Mound	Calc.	Mound	Calc.	Mound	calc.	
ARCHAEOCYATHIDS											
Cones/Sticks	A	SD	A	SD	C	--	A	SD	A	SD	
<u>Retilamina</u>	--	--	A	--	R	--	A	--	C	--	
TRILOBITES	R	P	P	C	R	C	P	P	P	C	
BRACHIOPODS	P	C	C	C	--	C/A	P	P	P	P	
COELENTERATE	A	--	C	--	P	--	--	--	--	--	
RENALCID ALGAE	--	--	A	--	--	--	C/A	--	A	--	
<u>Epiphyton</u>	--	--	R	--	--	--	R	--	R	--	
<u>Girvanella</u>	--	--	C/A	--	P	--	C/A	--	C/A	P	KEY
NON-SKELETAL											-- - Absent
STOMATOLITES	R	--	P	--	--	--	A	--	--	--	R - Rare
<u>Trypanites</u>	A	--	C	--	--	--	P	--	--	--	P - Present
SPONGE SPICULES	--	--	R	--	--	--	R	--	R	--	C - Common
ECHINODERMS	SD	A	C	A	SD	P	SD	A	SD	A	A - Abundant
HYOLITHIDS	--	P	P	P	R	P	--	R	--	P	SD - Skeletal debris
<u>Salterella</u>	--	--	--	--	--	--	--	--	--	C/A	
FORAMINIFERA	--	--	P	--	--	--	P	--	P	--	
<u>Archaeotrypa</u>	--	--	R	--	--	--	--	--	--	--	
BURROWS (?WORMS)	--	--	P	--	--	--	C	--	P	--	
<u>Bija</u>	--	--	P	--	--	--	--	--	--	--	

was hoped to ascertain whether certain parameters could be correlated with environment. Counts were made in four of the five lithofacies. Because of the badly weathered surfaces and stylonodular structure of the Nodular Moundstone (BN-1) no count was possible, although it was noted that forms present appeared to be large diameter wide cones, funnels, or bowls.

The diversity of archaeocyathid taxa in the Biostrome Facies is very low, consisting predominantly of Metaldetes profundus, Archaeocyathus atlanticus and a new genus and morphotype, Retilamina amourensis (Debrenne and James, in prep.). Retilamina is dome-shaped to sheet-like, single-walled with a reticulate skeleton, and an upper surface which has large pores. Secondary thickening of the wall is common. Individuals can be up to several centimetres long but the wall is only 1 - 2 mm thick (Figs. 45 and 57).

When the relative proportion of stick-forms (M. profundus and A. atlanticus) against cone-forms (M. profundus) is plotted for each lithofacies, a trend is seen (see Fig. 46). The lower outcrops of Grey Moundstone at Blanc Sablon consists of sticks and cones in a ratio of 8:1; the Red Moundstone consists of sticks and cones in roughly equal proportions, while the Dolomitic Moundstone has sticks and cones in a ratio of 1:10. This gives a further indication of the distinction between the five lithofacies.

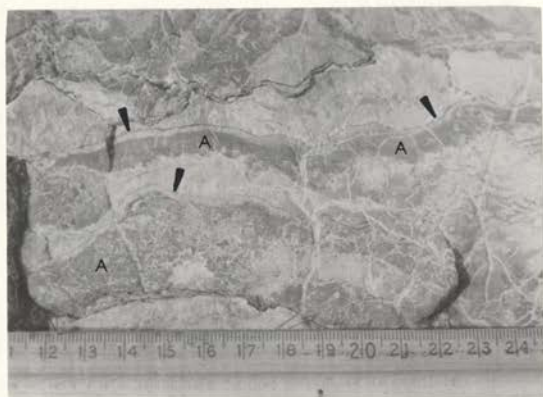


Fig.45: Cliff-section exposure of the Grey Moundstone lithofacies (BG-1) at Diversion Reef. Laminar Relilamina (arrowed) support a pendant growth of calcareous algae (dark areas, labelled A) beneath them. The lighter areas consist of lime-mud matrix. Scale is in centimetres.

- X - Dolomitic Moundstone lithofacies (BD-1)
- - Red Moundstone lithofacies (BR-1)
- - Archaeocyathid Bioherm lithofacies (BB-2)
- + - Grey Moundstone lithofacies (BG-1)

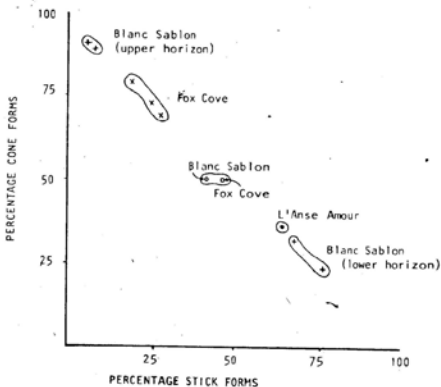


Fig. 46: Plot of relative percentage of cones versus sticks in various lithofacies.

although it is not clear at the moment what were the controlling factors in the distribution of archaeocyathid morphotypes between lithofacies. For the purpose of the synecology, however, archaeocyathids are considered as sessile, benthonic organisms feeding out of the water column, probably by filtering (Hill, 1964; Balsam, 1973).

Calcareous algae

Renalcis, renalcid algae, and Epiphyton

The calcareous algae Renalcis, Epiphyton, and a Renalcis-like organism (herein termed renalcid) are restricted to the mounds and have the same ecological function, so are described together. Preliminary notes on their affinities and previously described paleoecology are given separately, however.

Renalcis (Vologdin) consists of hollow, inflated chambers with thick calcareous walls and can occur either as individual chambers or as botryoidal aggregates (Riding and Toomey, 1972) (Fig. 47). Although this organism has a world-wide distribution and is quantitatively very important in Paleozoic reefs (Riding and Toomey, 1972; Wray, 1977) the biological affinities of Renalcis are still uncertain. Several authors believe that Renalcis is a foraminiferan (Elias, 1950; Riding, 1972; Riding and Brasier, 1975) on the basis that the size and morphology is consistent with Foraminifera, and that the chambers are an order of magnitude larger than those associated with

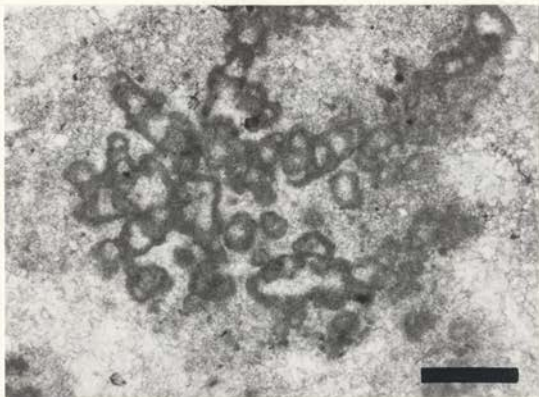


Fig.47: Photomicrograph (plane light) of a clump of chambered Renalcis occurring in the Red Moundstone lithofacies (BR-1). Scale bar is 0.3mm.

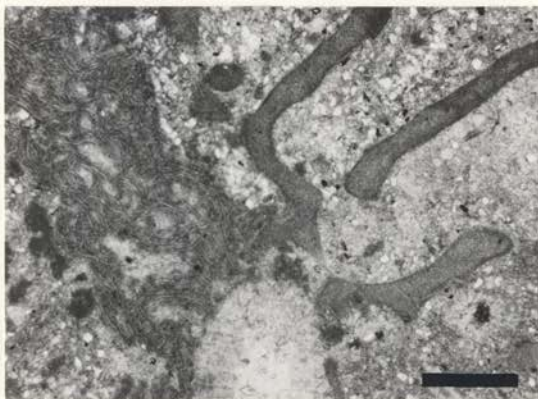


Fig.48: Photomicrograph (plane light) of tubules of Girvanella encrusting the central cavity of an overturned archaeocyathid (right). Note the penetration of Girvanella by the macro-boring ichnofossil Trypanites (bottom centre). Scale bar is 0.45 mm.

blue-green algae (see discussion in Riding and Brasier, 1975). They are therefore considered as a separate family (Renalcidae, n. fam.) of the Parathuramminacea (Riding and Brasier, 1975). On the other hand, they are often considered as blue-green algae (Korde, 1973; Hofmann, 1975) or at least problematical blue-green algae (Wray, 1977). A recent work (Brasier, 1977) illustrates well-preserved Renalcis in oncolites from the Eilean Dubh Formation of the Durness Group (Lower Cambrian) in Scotland. Brasier (1977) describes the walls as consisting of a chain of minute coccoid cells with the packing of the cells reducing towards the central chamber. Brasier (1977) concludes that these resemble colonies of coccoid cyanophytes (blue-green algae) embedded in a gelatinous envelope, but concedes that Renalcis may be an artificial or polygot genus (Brasier, 1977). In the light of this study, Renalcis is considered here as a cyanophyte (blue-green algae).

Epiphyton (Bornemann) consists of densely branched calcareous thalli with no discernable internal structure and is generally less than one mm in overall dimensions (Riding and Toomey, 1972; Wray, 1977). It is placed in the Cyanophyta (as problematical blue-green algae) by Wray (1977) because of the resemblance to Renalcis, the lack of micro-structure in most specimens, and the non-definitive illustration of claimed microstructure.

Epiphyton is generally considered a member of the Rhodophyta (Red algae) by most authors (Riding and Wray, 1972; Riding and Toomey, 1972; Korde, 1973), based on the cellular microstructure with cell-wall pores and sporangia, noted by Korde (in Wray, 1977), and this interpretation is followed in this study.

Epiphyton and Renalcis commonly occur in the Lower Cambrian (Korde, 1973; Brasier, 1976; Zammareño, 1977; James and Kobluk, 1978) sometimes forming algal mounds, and also occurring in massive algal limestone (Zammareño, 1977). In Lower Ordovician mounds, Epiphyton and Renalcis are mutually associated as sediment binders and stabilizers by forming dense clusters in sediment between and surrounding the mound forming organisms Archaeoscyphia and Calathium, but preferring a firm substrate (Riding and Toomey, 1972). Renalcis also encrusts other organisms but it is not certain whether Epiphyton, encrusts in the same fashion. Both Renalcis and Para-epiphyton (later placed as junior synonym of Epiphyton (Riding and Wray, 1972)) are regarded as good indicators of reef facies in the Upper Devonian, where they occur as encrusters, sediment stabilizers and binders (Wray, 1972).

Zhuravleva (1960, in Hill, 1972) claims that Renalcis and Epiphyton are mutually exclusive, with Renalcis occurring with archaeocyathids at depths down to 50 m and Epiphyton occurring with archaeocyathids at depths between 50-100 m,

although Riding (1975) questions the association.

Following Kobluk and James (in prep.), an organism similar to both Renalcis and Epiphyton is referred to as renalcid algae. It resembles Renalcis in size, mode of growth, and occurrence but differs in being unchambered, more arborescent, and branching. It resembles Epiphyton in being branched, unchambered, and arborescent but differs in being larger (Figs. 57 and 58). The renalcid algae always occurs with Renalcis, so in the following text the two organisms are both referred to as renalcid algae unless stated otherwise.

The paleoecology of renalcid algae and Epiphyton is essentially the same in the Biostrome Facies of the Forteau Formation. They are all restricted to moundstone lithofacies and are completely absent from the flanking calcarenites. They are, however, totally absent from the Dolomitic Moundstone (BD-1) and the Nodular Moundstone (BN-1) but abundant in the other three moundstone lithofacies (BR-1, BG-1, BB-2). This pattern of occurrence is the same as the distribution of Retilamina with which the calcareous algae are always intimately associated (Figs. 45 and 57), although they do occur in other situations as well. In all occurrences, renalcid algae are the most common. Epiphyton is considered rare although this may be due to the difficulty in separating the organism within dense growths of renalcid algae.

The main habitat of calcareous algae is in cavities,

growing as pendants from the undersides of Retilamina (Figs. 45 and 57) which forms the roof of the cavities. These algae also commonly occur as thin (several millimetres maximum) encrustations on the outside of archaeocyathid cups and coelenterate skeletons but often have geostrophic growth, with thickest accumulations on the bases of skeletons.

The role of the calcareous algae in the mounds is envisaged as being two-fold. They are the primary producers (autotrophs) in the trophic structure in the mounds, and also act as sediment stabilizers and binders when they occur on the outside of skeletons (cf. Riding and Toomey, 1972).

Girvanella

Girvanella (Nicholson and Etheridge) is a flexuous, tubular filament of uniform diameter, composed of relatively thick calcareous walls and is generally accepted as a member of the Cyanophyta (blue-green algae) (Wray, 1977), although it has also been considered as a Foraminifera, sponge, or green alga (see discussion in Riding, 1975). Girvanella has often been placed more precisely into the family Oscillatoriaceae (e.g. Lauritzen and Worsley, 1974), but probably represents the remains of numerous taxa possibly belonging to several families of blue-green algae (Riding, 1975; Wray, 1977), particularly when it is considered that most of the features by which

extant blue-green algae are classified are lost during fossilization (Riding, 1975; 1977a).

The recorded geologic range of Girvanella extends from the Cambrian to the Cretaceous (Riding, 1975), though extant forms are being documented (Riding, 1977a; Kobluk and Risk, 1977). Most of the fossil forms of Girvanella are from marine sediments although freshwater forms from Cretaceous lacustrine limestones are known (Colin and Vachard, 1977). Girvanella is often used as a shallow-water depth indicator but this may be suspect if Girvanella is indeed representative of a number of taxa, each with its own tolerances (Riding, 1975). However, it has been cautiously suggested that the prostrate growth form of Girvanella (Agathidia) compared with the erect growth form of the morphologically similar Ortonella (Thamnidia) may indicate that Girvanella inhabits high light availability areas (implying shallow-water) whereas the phototrophic growth of Ortonella suggests physical confinement as regards light availability (and hence sometimes, but not always, deeper water) (Riding, 1977a).

Girvanella has been described from many environments and as performing many roles in its geologic history. It is commonly found as an encruster and binder in back-reef environments in the Silurian (Lauritzen and Worsley, 1974) and Devonian (Wray, 1972). It is documented as an

endolithic (boring) organism in the Lower Ordovician (Klement and Toomey, 1967), and occurs in clusters or 'nests' in the back-reef environment in the Silurian (Lauritzen and Worsley, 1974). Girvanella is commonly the chief component in skeletal stromatolites (term after Riding, 1977b) in the Upper Cambrian (Ahr, 1971; Chafetz, 1973), where it also forms bioherms. In these bioherms Girvanella has a dendritic growth form which baffles sediment by growing vertically in tangles of almost straight tubules to form a series of bushes up to five cm high which together constitute a bioherm (Ahr, 1971).

Girvanella occurs in the Biostrome Facies and also the Oolite Sand Facies in a variety of modes of life: (1) encrusting onto skeletons; (2) as skeletal stromatolites and oncolites; (3) in 'nests' or clusters; (4) as an endolith.

Encrusting Girvanella: The most common mode of occurrence for Girvanella is as thin encrustations onto other skeletons, particularly archaeocyathids (Fig. 48). This occurs in all of the moundstone lithofacies except the Dolomitic Moundstone (BD-1) and is particularly common in Red Moundstone (BR-1). More commonly, Girvanella encrusts the top and sides of archaeocyathids but it also occurs as a coelobitic encruster on the undersides of Retilamina. Girvanella occasionally encrusts the upper surface of trilobites in skeletal grainstone, mixed peloid

packstone and mixed oncologic grainstone of the Oolite Sand Facies.

Girvanella as skeletal, stromatolites and oncolites:

The microstructure of some of the stromatolites in the Grey Moundstone (BG-1) and the Oolite Bioherm lithofacies (BB-1) consists of Girvanella tubules. At the top of the section at L'Anse Amour, Girvanella stromatolites have a structure consisting of laterally linked hemispheroids with close lateral linkage (LLH-C of Logan et al., 1964). The microstructure consists of prostrate Girvanella tubules which cumulatively form vertical bush-like structures that possibly had the ability to baffle sediment. The Girvanella stromatolites embedded in Oolitic Calcareenites (BB-1) form small ovoids in plan (diameter of several centimetres) and have a structure of laterally linked hemispheroids with spaced lateral linkage. This grades vertically (within one cm) into laterally linked hemispheroids with close lateral linkage (LLH-S/LLH-C of Logan et al., 1964). The type LLH structure is interpreted from modern studies to occur in the marine, intertidal mudflat environment, mainly in protected re-entrant bays and behind barrier islands and ridges where wave-action is usually slight (Logan et al., 1964).

Girvanella oncolites occur commonly in the mixed oncologic grainstones of the Oolite Sand Facies (Fig. 49) where they have a structure of concentrically stacked

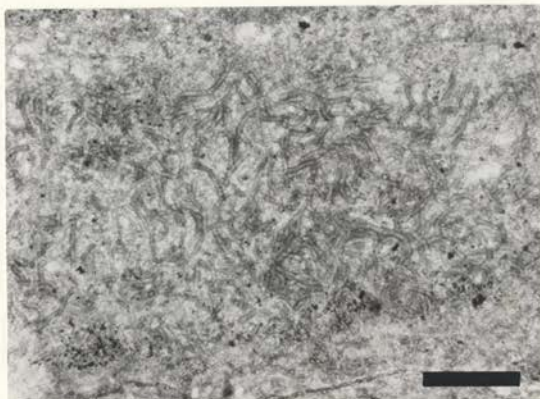


Fig.49: Photomicrograph (plane light) of Girvanella occurring at the centre of an oncolite in the mixed oncolite grainstone lithology. The oncolite enlarged here is the same as that illustrated at the top of Fig.14. Scale bar is 0.3mm.

spheroids (SS-C of Logan et al., 1964), normally around a nucleus of a compound grain (grapestone). Up to three periods of growth are indicated in some of the oncolites (Fig.21). Type SS-C structures indicate continual motion to achieve concentrically stacked spheroidal laminations suggesting a high-energy environment for the mixed oncogenic grainstone (Ginsburg, 1960; Logan et al., 1964).

'Nests' or clusters of Girvanella: Rare occurrences of spheroidal clusters of intertwined tubules of Girvanella occur as aggregates up to several millimetres across in some of the mounds. A similar morphology occurs in the intraclast grainstone of the Oolite Sand Facies (Fig.22) but these may be formed by transportation.

Girvanella as Endoliths: An isolated occurrence of Girvanella as an endolithic organism is seen in the mixed oncogenic grainstone of the Oolite Sand Facies where one half of an echinoderm plate now consists entirely of intertwined tubules of Girvanella while the other half remains unaltered (Fig.50).

Non-Skeletal Stromatolites.

The only non-skeletal stromatolites (term after Riding, 1977b) in the Biostrome Facies are small (less than one cm high), vertical stacked hemispheroids with a variable basal radius (type SH-V of Logan et al., 1964). They commonly occur in groups in the Grey Moundstone (BG-1) at Blanc Sablon (Fig.27) but occur rarely as isolated stacks in the Dolomitic Moundstone (BD-1) and

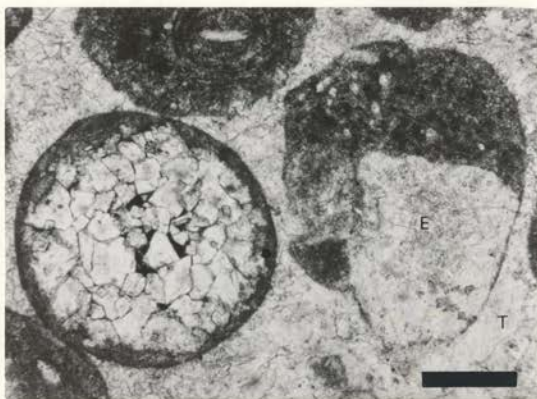


Fig.50: Photomicrograph (plane light) of the mixed oncolite grainstone lithology. The top part of the ?echinoderm fragment (E) has been micritized by the endolithic activity of Girvanella, tubules of which can still be seen. Note that syntaxial cement (T) occurs on parts of the fragment not bored into but is inhibited on the micritized part of the fragment. The ooid (left) has been dolomitized by numerous, small, dolomite rhombs. Note the dark outer layer of the ooid. Scale bar is 0.4 mm.

the Red Moundstone (BR-2) at Fox Cove.

Coelenterate.

A new, primitive coelenterate (?) occurs sporadically in the Biostrome Facies. The skeleton, currently being described by Kobluk and Sorauf (in prep.) consists of highly branched fronds up to 10 cm long, each branch tapering to a point (Figs. 51 and 52). The internal structure is not visible as the original skeleton has been dissolved and the resultant void filled with cement (Fig. 52).

The distribution of the coelenterate is very irregular. It is very abundant in the northern outcrop of the Dolomitic Moundstone (BD-1) at Fox Cove, but is absent from equivalent strata 300 m to the south. It also occurs in the Dolomitic Moundstone (BD-1) in the cliffs at L'Anse Amour. It occurs throughout the Red Moundstone (BR-1), particularly in a colonization assemblage (see below), but is rare in the Nodular Moundstone (BN-1), and is absent from the Grey Moundstone (BG-1) and Oolite Bioherms (BB-2).

The role of the coelenterate in the mound structure is uncertain. The branched morphology appears to grow either horizontally along the sediment or downwards, although an attachment point is not seen. Its morphology suggests that it trapped sediment within its branches which were also used as attachment points for pendant calcareous algae.



Fig.51: Cliff-section of Dolomitic Moundstone (BD-1). A frond of the coelenterate organism (X) lies below three archaeocyathid (Metaldetes) cups. Scale bar is in centimetres.

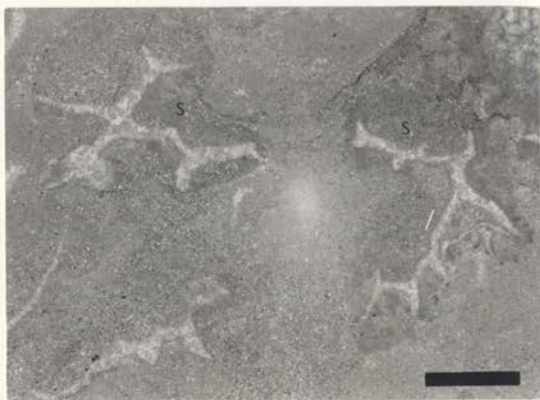


Fig.52: Photomicrograph (cross-polarized light) illustrating skeletons of the coelenterate organism in Red Moundstone (BR-1). The skeletons have been leached and infilled by pore-fill cement. The matrix was lime-mud (now microspar) with a proportion of quartz silt. The dark sediment (S) surrounding some of coelenterate fronds may be stromatolitic in origin. Scale bar is 2.5 mm.

Brachiopods.

Early Cambrian brachiopods are a moderately large, quite complex (not primitive), diverse group of organisms which bear witness to a major phase of evolutionary radiation (Rudwick, 1970). Inarticulate brachiopods are more common than articulates in the Cambrian, particularly in the Lower Cambrian where five inarticulate superfamilies are known and only two articulate superfamilies. Schuchert and Dunbar (1934) list six species of brachiopods from the Porteau Formation but Fong (1967) and Balsam (1973) list only three: Obelella chromatica, Kutorgia cingulata (both inarticulate) and Nisusia oriens (an orthisid articulate).

Ecologically, recent brachiopods can be described as bivalved, sessile benthonic, epifaunal (permanently attached), low-level filter-feeders (lophophorates). The feeding system of fossil brachiopods can be interpreted to be functionally the same as extant forms (Rudwick, 1970) suggesting that fossil forms are ecologically similar to the living forms. The ingestion and digestion of inarticulates is essentially the same as the articulates, differing only in the exulsion of waste (articulates through the mouth, inarticulates through the anus) and the food is the same, both classes having the ability to assimilate dissolved substance plus bacteria, colloids, organic detritus and algae (Steele-Petrović, 1976). The food of fossil brachiopods was

probably the same as extant forms (Steele-Petrović, 1976). Brachiopods are attached to the substrate by a pedicle or by cementation (Rudwick, 1970), but the Lower Cambrian forms, particularly Obelella, had a pedicle attachment (Balsam, 1973).

Brachiopods are reported from "reef-like" environments throughout the Phanerozoic. Although a minor phylum today, they are present in modern reefs, but occupy a coelobitic habitat (Jackson, Goreau and Hartman, 1971; Logan, 1977), and only emerge from these cryptic environments with increasing depth (Logan, 1977). Inarticulate, acrotretide brachiopods show great diversity (17 genera) in the Ordovician Meiklejohn mounds of Nevada, reflecting the adaptation into numerous microhabitats (Rowell and Krause, 1972).

In the Biostrome Facies of the Forteau Formation, brachiopods, particularly Obelella, are found sporadically in both moundstones and calcarenites. In the moundstone, Obelella and rarely Nisusia occur as isolated individuals and are noticeably more common where there is an abundance of calcareous algae, especially in the Red Moundstone (BR-1). They may have attached themselves to calcareous algae as suggested from their occurrence in the Ordovician Meiklejohn mound (Rowell and Krause, 1972). There is no evidence for their attachment in this mode in the rocks under study, but this is not usual as the soft pedicle rots away upon death (Rudwick, 1970). They were not found in a coelobitic habitat.

Brachiopods are the chief skeletal component, along with echinoderms, of isolated pockets (small lenses) of skeletal calcarenite occurring within the Dolomitic Moundstone (BD-1), Red Moundstone (BR-1), and Nodular Moundstone (BN-1) and probably represent areas within the mounds favouring brachiopods and echinoderms.

Brachiopods are considerably more common in the flanking skeletal calcarenites where they occur as unbroken, disarticulated valves, either singly or in "nests" suggesting a gregarious mode of life. It is, however, important to differentiate between life and death assemblages. This is difficult with inarticulate brachiopods as the shells become disarticulated upon death (Ager, 1967). The individual, disarticulated valves of the "nests" are unbroken and show no other signs of wear suggesting that transport was minimal.

It is considered therefore, that brachiopods in the Biostrome Facies occurred as single individuals in the mounds possibly attached to calcareous algae, and occurred as both single individuals or in nests or pockets of calcarenite in the mounds and in the flanking calcarenites. In both cases they were low-level filter feeders.

Trilobites.

Lower Cambrian trilobites are a very complex and diverse group of organisms with 4 orders and 24 families (Harrington, 1959). In the Biostrome Facies the only

genera recognised are Bonnia sp. (fam. Dorypygidae) and Wanneria sp. (fam. Olenellidae) although a third form, seen only in thin-section, may be another taxon.

In spite of the abundance of trilobites in the fossil record and the vast amount of taxonomic data on them, little is known of their paleoecology. It is possible however, that their mode of life may be deduced from their functional morphology (Bergström, 1973).

The main morphological features of Bonnia are: a wide rhachis (axis); a smooth exterior; a highly convex, isopygous body, particularly the cephalon; and small eyes. The wide rhachis allows plenty of room for appendages and muscles so that the animal had considerable power, useful for a swimmer, crawler, or burrower. The smooth exoskeleton would cut down the friction if the animal was a swimmer and would keep sediment from adhering to the skeleton if it was a burrower. The highly convex shape would be a restriction to a swimmer, but not to a burrower. The isopygous skeleton may suggest that the muscle power was evenly distributed, possibly allowing the animal to burrow backwards into the sediment as suggested for trilobites with similar morphologies to Bonnia (Bergström, 1973). It is likely therefore that Bonnia was a burrower, and as Bergström (1973) suggests for similar trilobites, the cephalon may have rested on the surface while the thorax and pygidium were inclined (not vertically) into the substrate. Burrows were not seen in the sediment studied but they are not often

preserved (Bergström, 1973; p.62). Bonnia appears to be restricted to the moundstone where it probably burrowed and lived on food within the sediment. Many similar trilobite morphologies have been found in reef-rocks of the Middle and Upper Ordovician of Sweden (in Bergström, 1973).

Wanneria is characterized by a reticulate network of raised lines on the skeleton which distinguish it from Olenellus in the field. Its main morphological features are: an elongate, micropygous exoskeleton which is nearly flat or with low convexity; large eyes; long genal spines; a wide cephalon; and a narrow pygidium (the axis tapers from cephalon to pygidium). A tapering exoskeleton suggests that the muscles and appendages were concentrated towards the front of the animal, possibly indicating that the organism crawled along the surface or burrowed head first. The long genal spines and general spinose nature of the organism precludes a burrowing or swimming habit, but not a crawling habit. The large eyes suggest that the animal either searched selectively for food or was prone to attack from predators and used them for warning of attacks. It is probable that Wanneria was part of the mobile benthos, possibly a scavenger or deposit feeder. It was restricted in its distribution to the flanking calcarenites.

The third trilobite, seen only in thin-section,

(Fig.53) is very small (1 mm across) with a highly convex carapace and occurs only within the internal sediment of cavities. They are however, not spinose as are the coelobitic trilobites of lower patch reefs (Kobluk and James, in prep.). Not enough is known of their morphology to infer a mode of life but they must have lived either on or within (as burrowers) the internal sediment, probably as scavengers or deposit feeders.

Hyolithids

Hyolithids are extinct, biperulate, bilaterally symmetrical animals with a calcareous, ventrally flattened, conical shell, and are of uncertain affinities (Runnegar, Pojeta, Morris, Taylor, Taylor and McClung, 1975). They are either considered a separate phylum but related to the Mollusca or Sipunculoidea (Runnegar et al., 1975) or are placed as separate class in the phylum Mollusca (Yochelson, 1961; Marek and Yochelson, 1976).

The hyolithid skeleton consists of three parts:

- (1) An elongate cone
- (2) A close-fitting operculum
- (3) Two narrow, dorsally curved appendages which project from slots between the operculum and shell on opposite sides of the organism. The arrangement of the muscle scars suggest that the head could be protracted or retracted, the operculum could open and close, and appendages could be moved (Runnegar et al., 1975).



Fig.53: Photomicrograph (plane light) of internal sediment in a cavity formed by Retilamina in Red Moundstone (BR-1). Sediment was lime-mud (now microspar). Note small, highly convex, trilobite carapaces. The lighter areas (now spar) were probably small worm burrows. Scale bar is 0.45 mm.

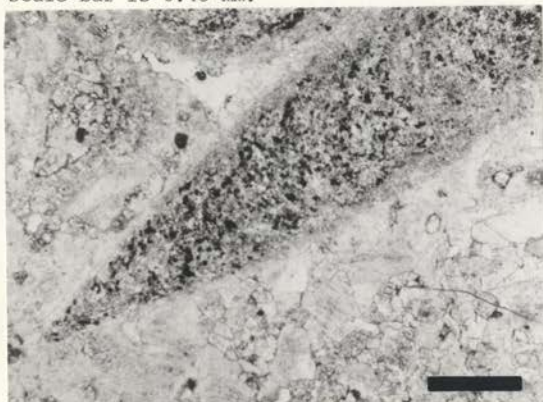


Fig.54: Photomicrograph (plane light) of a Salterella cone in skeletal grainstone of the Oolite Sand Facies. Scale bar is 0.45 mm.

The function of the two appendages is controversial. They may have been used as oars in a rowing action to propel the organism along (Runnegar et al., 1975) although there are no special muscles to suggest this (Marek and Yochelson, 1976). Yochelson (1974) claims that the appendages acted as stabilizers giving the animal lateral stability. If movement of any kind involved the appendages then it would have been slow and sporadic, and of the order of a few millimetres at a time (Marek and Yochelson, 1976). The presence of sediment in the gut of well-preserved specimens suggests a deposit-feeding mode of life (Runnegar et al., 1975) with a most plausible food source of mixed detritus and micro-organisms living on or within the sediment-water interface (Marek and Yochelson, 1976). The food was most likely collected by either a short proboscis that projected ventrally between the operculum and cone (Runnegar et al., 1975) or by tentacles, which would have also facilitated movement (Marek and Yochelson, 1976).

Hyalolithids occur in both the moundstones and calcarenites, particularly the more muddy calcarenite lithologies, where they were probably semi-sessile omnivorous deposit feeders. Their distribution is inverse to the distribution of preserved calcareous algae suggesting that they are deposit feeders and not algal browsers as suggested by Balsam (1973).

Echinoderms.

Four classes of primitive echinoderms are recognised from the Lower Cambrian; Eocrinoidea (Blastozoa), Helicoplatoidea, Edrioasteroidea and Camptostromatoidea (all Echinozoa). This initial explosive radiation in the Lower Cambrian suggests that there was considerable Precambrian evolution of this group (Durham, 1964) which allowed diversification of the basic morphological design when the organisms colonized a new environment in the Lower Cambrian and adapted to a novel mode of life (Paul, 1977).

All of the Lower Cambrian classes were morphologically inefficient (Paul, 1977). They consisted of a flexible theca of imbricated plates, although the eocrinoids had a small oral surface of weakly tessellated plates. The relatively large theca and small exchange surfaces for oxygen and carbon dioxide suggests that respiration was inefficient (Paul, 1977). The large theca also indicates a large food requirement but with the small filter area available on Lower Cambrian echinoderms (see Paul, 1977; p. 138) then feeding must also have been very inefficient.

Paul (1977) regards all of the Lower Cambrian echinoderm classes as being filter-feeders but Sprinkle (1976) regards the camptostromatoids (only one genus known from the Lower Cambrian) as part of the mobile benthos or as shallow burrowing detritus feeders while eocrinoids are high-level filter feeders, and helicoplatoidea and edrioasteroids are low-level filter feeders.

The size of the food grooves in the food-gathering brachioles and ambulacra of the eocrinoids suggests that the food was microscopic plankton. The eocrinoids were therefore microphagous high-level filter feeders living in an upright position with a long attachment appendage (holdfast) at the aboral end supporting a globular calyx with mouth, ambulacral arms and food-gathering concentrated at the summit (Sprinkle, 1973). The eocrinoids were also gregarious, living in "gardens" situated at favourable localities for feeding, attachment, or reproduction (Sprinkle, 1973).

In the rocks under study, only disarticulated plates of echinoderms are preserved so no taxa are identifiable. This suggests that the echinoderms were not rapidly buried as they possess skeletons which usually disintegrate rapidly after death (Paul, 1977), so are only preserved as whole skeletons upon rapid burial (Sprinkle, 1973). In the Biostrome Facies, the disarticulated plates make up a very large proportion of the mound-flanking skeletal calcarenites and are locally abundant in Red Moundstone (BR-1) at Blanc Sablon, but are absent from the rest of the moundstones except as skeletal debris which was probably washed in. They do however, occur in the small lenses of calcarenite which occur within some of the mounds.

The echinoderms can therefore be said to be a ubiquitous member of the sands flanking the archaeocyathid

mounds where they were probably high-level filter feeders forming gardens, and also occurred in favourable positions within the mound, along with other skeletal fauna (brachiopods, trilobites, etc.), but were absent or very rare from most of the mound.

Salterella

Salterella sp. (Fig. 54) consists of a normally radially symmetrical, simple cone of calcium carbonate, which has grains, selected for size and shape, placed layer by layer within it, and each layer of grains is held in place by a thin layer of calcium carbonate. The apical part of the cone is filled except for a central tube of uniform diameter (Yochelson, 1977).

The affinities of Salterella are in doubt; Yochelson (1977) places the genus, along with another closely related genus Volborthella, in a new phylum, Agmata, although Volborthella has also been ascribed to the phylum Annelida (Glaessner, 1976).

Ecologically, Salterella has a functional morphology which does not have a suitable ecological niche. It has a geographical distribution throughout the Appalachians but is apparently restricted to the top portion of the Bonnia-Olenellus zone of the Lower Cambrian (Yochelson, 1970). Using sedimentological evidence, Salterella inhabited environments which demonstrated a wide range of energies but were predominantly shallow-water, with depths between a few centimetres and a few metres (Yochelson,

1977). The presence of selected grains in the conch and absence of buoyancy structures rules out a pelagic or nektonic mode of life as their weight would have been too great. Glaessner (1976) draws the analogy between the closely related Volborthella and the sabellariid worms and suggests that Volborthella lived apex downward in the sediment with the top part exposed and was a filter-feeder which also picked silt-size grains out of the water-column as they drifted past. But Yochelson (1977) correctly points out that any current strong enough to carry silt would also be strong enough either to wash the small animal from the sea-floor or smother it completely. The mode of life has been compared to cerithid gastropods (Reinhardt and Wall, 1975). This is based on similarities of gross shell-shape and death assemblages. However, the functional morphology of the two animals differs too much for a direct comparison to be made. A mobile life-style is suggested, particularly as grains in the conch are often rare in the sediment matrix suggesting that the animal moved towards, and selected particular grains. Contrary to this hypothesis however, is the filling of the cone which would indicate that the organism may have lived apex down and that if Salterella was mobile then the conch would have to be dragged along (Yochelson, 1977). It seems likely therefore, that whatever mode of life was utilized by Salterella it was very inefficient.

Although common in the skeletal grainstone, mixed peloid packstone, and mixed oncolitic grainstone lithologies of the Oolite Sand Facies, Salterella is absent from the moundstone and calcarenites of the Biostrome Facies, occurring only in the Oolitic Calcarenites (BB-1) which flank the Bioherms (BB-2) at Schooner Cove. In this lithofacies Salterella is very abundant adjacent to the bioherms (within 2 m) but becomes rarer away from them, possibly suggesting a greater food source nearer to, and possibly derived from, the bioherms. It is envisaged therefore that the Salterella was a very inefficient member of the mobile benthos, possibly a browser or deposit-feeder.

SYNECOLOGY

Mound-flanking Skeletal Calcarenite faunal assemblage

The term assemblage is preferred to community as this is only a qualitative description and the taxa involved are only identified on a very broad scale (never to the species level).

The assemblages are documented with a view to the role of the organisms in the assemblage and to their trophic grouping, so that a general, summary-like structure of the various assemblages can be presented forming a basis for future detailed analysis with tighter taxonomic control.

The skeletal composition of the flanking calcarenites is more or less the same for each lithofacies, consisting of five groups of organisms; echinoderms, brachiopods,

trilobites, hyolithids, and Salterella. Based on their autecology, these organisms can be divided into sessile epifauna and vagile epifauna (see Table V). The sessile epifauna consists of echinoderms and brachiopods and can be regarded as high and low-level filter suspension feeders respectively thus partitioning the food supply. The vagile epifauna consisting of trilobites, hyolithids, and Salterella can be considered as sediment dependent organisms; either deposit feeders or browsers. Volumetrically, echinoderm plates form the bulk of the sediment with brachiopods and trilobites the next most important; hyolithids and particularly Salterella are rare. As regards the structure of the assemblage, the preserved trophic chain (Fig.55) is very simple lacking both primary producers (autotrophs) and predators. Bearing in mind that not all the organisms of the original community will have been preserved (see discussion in Stanton and Dodd, 1976), the dominance of filter-feeders within the assemblage suggests that the environment was, to some degree, turbid as the food supply to the majority of organisms was in the water column.

Mound-dwelling faunal assemblage

The faunal assemblages which inhabit the mound environment are generally more complex than the calcarenite assemblage. There are differences in the diversity of organisms between the five moundstone lithofacies, and these are noted later. Because of these differences, the most complex assemblage, that of the Red Moundstone

TABLE V. Role of organisms in the calcarenite assemblage.

ORGANISM-NICHE RELATIONSHIP

TROPHIC GROUP

Sessile epifauna

echinoderms

high-level filter
suspension feeders

brachiopods

low-level filter
suspension feeders

Vagile epifauna

trilobites

deposit feeders

hyolithids

deposit feeders

Salterella

deposit feeder

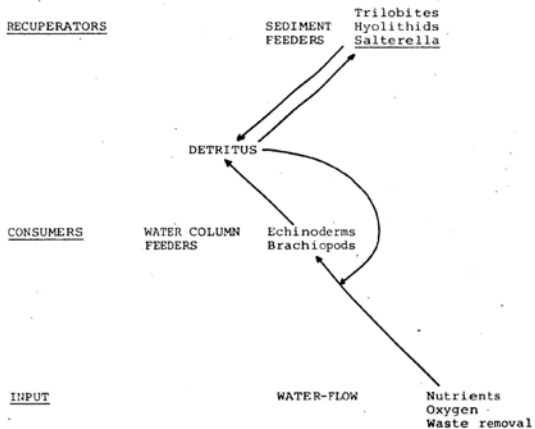


Fig.55: Trophic structure of the calcarenite assemblage.

lithofacies (BR-1)), is described here.

In relation to the substrate, the mound-organisms can be divided into; sessile epifauna, mobile epifauna, and endoliths (see Table VI). A division of the sessile epifauna can be made into organisms which probably acted as sediment bafflers and organisms which acted as sediment trappers and binders (Table VI). A more complex trophic structure is represented in the mound where primary producers, consumers, and recuperators are well-represented (Fig.56).

The main difference between the mound and calcarenite assemblages are two-fold: (1) the presence of different kinds of high-level suspension feeders; (2) the presence of calcareous algae in the mound.

The mound assemblage is dominated by archaeocyathids and calcareous algae (renalcid algae, Epiphyton, and Girvanella) with less common brachiopods, coelenterate, trilobites, hyolithids, and sponges. The archaeocyathids are of very low diversity with only three species represented (Metaldetes profundus, Archaeocyathus atlanticus, and Retilamina amourensis) (Debrenne and James in prep.). The erect growth form of archaeocyathids may have served as sediment bafflers along with rare sponges, the coelenterate and possibly brachiopods. Although calcareous algae is most common in cavities, it also grew in clumps in the sediment and encrusted onto and within the archaeocyathid skeletons where it probably trapped

TABLE VI. Role of organisms in the mound assemblage.

ORGANISM-NICHE RELATIONSHIP	TROPHIC GROUP
<u>Sessile epifauna</u>	
(1) Possible sediment bafflers	
archaeocyathids	high-level suspension feeders
coelenterates	?low/high-level suspension feeders
brachiopods	low-level filter suspension feeders
sponges	suspension feeders
(2) Sediment trappers and binders	
calcareous algae (outside of cavities)	autotrophs
<u>Renalcis</u>	
<u>renalcid algae</u>	
<u>Girvanella</u>	
<u>Epiphyton</u>	
non-skeletal stromatolites	autotrophs.
<u>Vagile epifauna</u>	
Hyalolithids	deposit feeders
?trilobites	deposit feeders.
<u>Infauna</u>	
trilobites	deposit feeders
<u>Endoliths</u>	
<u>Trypanites</u>	?

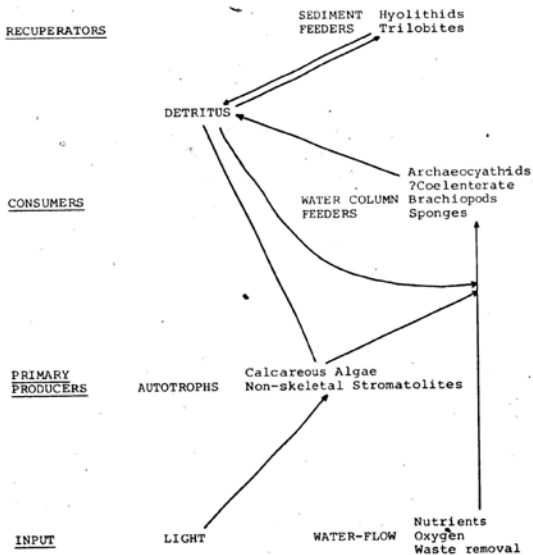


Fig. 56: Trophic structure of the mound assemblage.

and bound sediment. Semi-sessile hyolithids and burrowing trilobites (cf. Bonnina) may have been deposit feeders. Macroborers also played a role in the mound. The form Trypanites, interpreted as a sipunculid worm (James et al., 1977), is relatively common in most of the mounds but as it is the only macroborer in the rocks, and because of its relatively small size, the destruction of the mounds is nowhere near as great as in that of endolithic organisms in modern reefs (James 1970; Scoffin and Garrett, 1974; Bromley, 1978).

The trophic structure of the mound, although more complex than the calcarenite assemblage is still relatively simple (Fig.56). Calcareous algae and non-skeletal stromatolites acted as primary producers (autotrophs) supplying nutrients for the partitioned suspension feeders (consumers). Archaeocyathids, sponges, and some coelenterates were high-level suspension feeders while brachipods, smaller coelenterates, and possibly sipunculids (Trypanites) were low-level suspension feeders. Both autotrophs and consumers contributed nutrients to the sediment and in turn to the deposit feeders, trilobites, and hyolithids. No predators are recorded.

Coelobitic (cavity dwelling) assemblage

The dome-shaped nature of Retilamina amourensis forms a natural, although small (several centimetres high and wide) cavity which supports a relatively diverse coelobitic

assemblage, of similar structure to the cavity-dwelling assemblages found in the 'patch-reef' series (Kobluk and James, in prep.). Two substrate-niche relationships are recognised: (1) Organisms which attach themselves to the roof of the cavity; (2) Organisms which are found in the internal sediment (see Table VII).

Those organisms which are attached to the roof of the cavities include renalcid algae and rarely Epiphyton which grew in pendants resembling bunches of grapes. Girvanella occasionally encrusted directly onto the roof. Single-chambered and multi-chambered (cf. Wetheredella) Foraminifera either attached themselves directly onto the roof or were attached within clusters of calcareous algae. Encrusting archaeocyathids (Metalletes sp.) were also either attached directly onto the roof (Fig. 57) or within clusters of calcareous algae. The enigmatic forms Archaeotrypa and Bija were encrusted directly onto the cavity roof (Fig. 58). Both forms are characterized by an irregular cellular structure of tightly-packed rounded-polygonal cells, differing in that Archaeotrypa was larger, has more regular walls, and a skeleton that has always been leached and filled with cement (Fig. 58). Bija is considered either a coelenterate or an alga (Johnson, 1966). Archaeotrypa is also of doubtful affinities, considered either a bryozoan, or coelenterate (see discussion in Kobluk and James, in prep.).

Organisms inhabiting the internal sediment of the cavities included small (one mm), highly convex, non-

TABLE VII. Role of organisms in the coelobite (cavity dwelling) assemblage.

ORGANISM-NICHE RELATIONSHIP	TROPHIC GROUP
<u>Attached (cavity roof encrusters)</u>	
Calcareous algae	autotrophs
<u>Renalcis</u>	
renalcid algae	
<u>Girvanella</u>	
<u>Epiphyton</u>	
<u>Blja</u> (if alga)	
foraminifera	suspension feeders
archaeocyathids	suspension feeders
<u>Archaeotrypa</u>	suspension feeder
<u>Sediment dwellers</u>	
trilobites (infaunal)	deposit feeders
?worms (infaunal)	deposit feeders
sponges (epifaunal)	suspension feeders

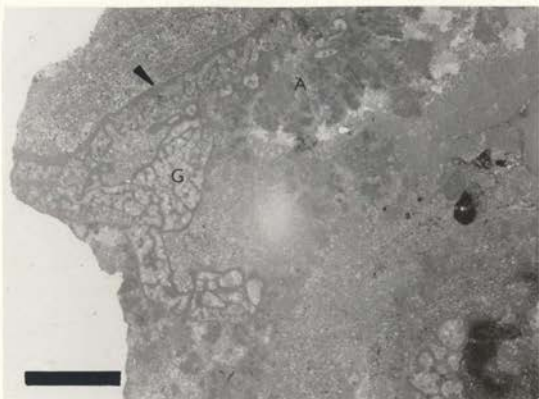


Fig.57: Photomicrograph (plane light) of Retilamina (arrowed) forming cavity. Encrusting archaeocyathid (G) and renalcid algae (A) are attached to the underside of Retilamina (the cavity roof) Scale bar is 3 mm.

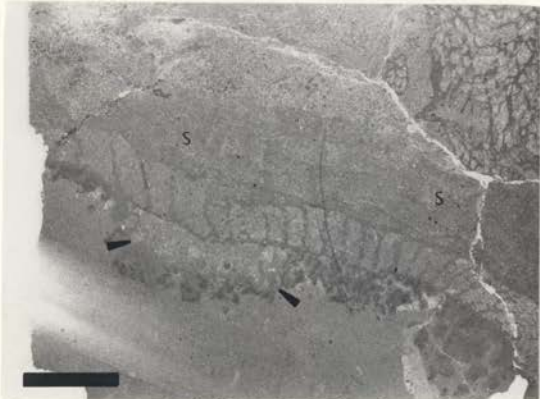


Fig.58: Photomicrograph (plane light) of an archaeocyathid forming a cavity. Renalcid algae and a leached (now spar) skeleton of Archaeotrypa (arrowed) encrust the underside of the archaeocyathid. Non-skeletal ?stromatolitic sediment (S) occurs on the top side of the archaeocyathid. Scale bar is 4 mm.

spinose trilobites (see Autecology: trilobites) which were probably burrowers. They occur only in the larger cavities. Sponge spicules (monaxon and triaxon) occur sporadically in the interral sediment and sponges may have inhabited the cavity. In cavities that are large enough, the internal sediment often contains small, cylindrical burrows, attributed, in the lower patch-reef series, to worms (Kobluk and James, in prep.).

The trophic structure of the coelobite assemblage is relatively complex (Fig.59). As primary producers (calcareous algae) form the bulk of the biovolume, then light must have been able to penetrate into the cavities. Organisms dependent on the water column (suspension feeders) include Foraminifera, archaococcythids, sponges, Archaeotrypa, and possibly Bija, and their presence implies that there was a constant exchange of water in and out of the cavity, bringing in nutrients and oxygen and removing waste. The trilobites and worms act as recuperators, either as scavengers or deposit feeders.

Vertical zonation in mounds

It has been established that more or less orderly changes occur in a community through time, thus causing a succession of communities preserved in the fossil record as a vertical zonation (Walker and Alberstadt, 1975). Such vertical zonations are documented from reefs from the Ordovician to Cretaceous (Nicol, 1962; Alberstadt and Walker, 1973; Alberstadt, Walker and Zurawski, 1974; Kauffmann, 1974; Walker and Alberstadt,

RECUPERATORS

SEDIMENT FEEDERS Worms
Trilobites

DETRITUS

CONSUMERS

WATER COLUMN
FEEDERS

Archaeocyathids
Foraminifera
Archaeotrypa
Sponges

PRIMARY
PRODUCERS

AUTOTROPHS Calcareous Algae

INPUT

LIGHT

WATER-FLOW

Nutrients
Oxygen
Waste removal

Fig. 59: Trophic structure of the coelobite (cavity dwelling) assemblage.

1975). Walker and Alberstadt (1975) recognise four stages of development, each characterized by its own community, in the development of vertical zonation in ancient reefs. These stages are: (1) Stabilization (pioneer) stage: This involves the stabilization of the substrate, usually by the growth of echinoderms and the accumulation of their debris; (2) Colonization stage: This involves the initial colonization of the substrate by reef-building organisms, normally by branching or encrusting organisms. This stage is normally of short duration; (3) Diversification stage: The increase in niche space brought about by the colonization stage leads to a rapid diversification, usually at high taxonomic levels, but is sometimes restricted within one major taxon. This stage comprises the bulk of the reef. (4) Domination stage: The final stage involves a decrease in both the number of taxa and in the growth-habits, often with the encrusting growth-habit dominating to the exclusion of others. Walker and Alberstadt (1975) claim that the first three stages; stabilization, colonization, and diversification are due to intrinsic factors, so that the succession is biologically accommodated. The fourth stage, domination, may be due to extrinsic factors, therefore physically induced and was maybe caused by the reef growing into the surf-zone.

The mounds of the Biostrome Facies sometimes show a distinct vertical zonation, correlatable with the

stabilization, colonization and diversification stages of Walker and Alberstadt (1975), but never show a domination stage. This may suggest that the Lower Cambrian mounds never grew into the surf-zone although sedimentological evidence possibly suggests otherwise.

The vertical zonation in the Biostrome Facies is best termed as a "recolonization process leading to diversification", and is best displayed at the base of the Red Moundstone (BR-1) at Fox Cove and at Osprey Reef. In all cases the succession appears to be the same (Fig. 60); a development of moundstone is brought to an end by an influx of skeletal calcarenite which occurs as a thin (less than 20 cm) bed, sometimes with an erosive base suggesting an allochthonous source (possibly a storm-deposit). The calcarenite consists predominantly of echinoderm debris with trilobites, brachiopods, and hyolithids. This is a similar lithology as would be produced by the stabilization community of Walker and Alberstadt (1975). This thin calcarenite bed is then succeeded by an assemblage dominated by Retilamina (Figs. 60 and 61) with minor occurrences of the coelenterate and stick-form archaeocyathids (Archaeocyathus atlanticus). Associated with the Retilamina is the coelobitic assemblage described above. All of the organisms in this assemblage occur in a lime-mud matrix, the mud probably being trapped by the closely packed Retilamina and coelenterate fronds along with, in places, calcareous algae. This colonization assemblage is relatively thin

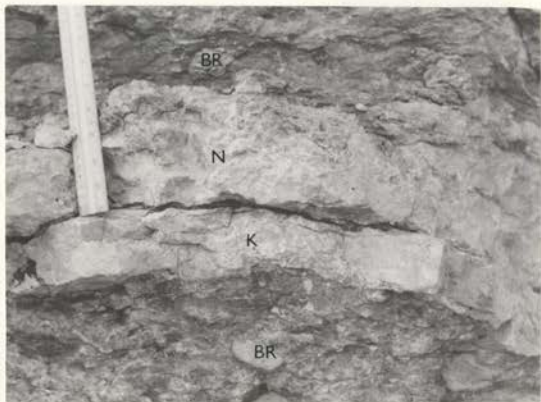


Fig.60: Cliff-section exposure of vertical zonation of the Red Mound Unit at Osprey Reef. Red Moundstone (BR, bottom) is terminated by a sheet of skeletal calcarenite (K). This is overlain by the pioneer community (N) consisting of mainly Retilamina and calcareous algae in a mudstone matrix. This passes vertically into Red Moundstone (BR, top). Scale is 25 cm long.



Fig.61: Bedding-plane exposure of the pioneer community of the Red Moundstone lithofacies (BR-1) at Fox Cove. Thin lines (arrowed) are Retilamina skeletons. Darker areas are calcareous algae; Lighter area is lime mud matrix. Scale bar is in centimetres.

D

(less than 30 cm) and grades vertically but rapidly into what can be termed the diversification stage (Fig. 60), which in the case of Red Moundstone consists of Metaldetes profundus (cone-form and stick-form), Archaeocyathus atlanticus (stick-form), and Retilamina amourensensis (retilaminiform) in equal proportions along with the coelenterate, sponges, calcareous algae, brachiopods, trilobites, and hyolithids, plus the coelobitic assemblage. This diversification assemblage forms the bulk of the mounds, as it does in the cases cited by Walker and Alberstadt (1975). No domination stage is seen in these rocks, instead the Red Moundstone passes vertically into Nodular Moundstone (BN-1) which consists of fewer archaeocyathids and a greatly reduced subsidiary fauna (see Table IV). This is treated as an allogenic phase as there is an obvious change in the style of sedimentation (into nodular limestones and shales with calcarenites) and is not considered as part of the vertical zonation.

As the calcarenite at the base of the succession is probably allochthonous in origin it can hardly be used as the stabilization assemblage in the sense of Walker and Alberstadt (1975). The calcarenite is not part of a biological succession, indeed its chief function was to terminate the development of the underlying moundstone as indicated by its erosive base in places. It is impossible to ascertain whether or not the calcarenite was still mobile when colonized by the Retilamina assemblage.

If the calcarenite was still mobile then the Retilamina assemblage must have served the dual purpose of stabilization and colonization. If on the other hand the calcarenite was stable at the time of colonization, then the Retilamina assemblage must have colonized a stabilized, allochthonous substrate. If this is the case with any of the other stabilization/colonization successions previously described, then the terminology of Walker and Alberstadt (1975) for this process needs slight modification or qualification.

Variation in fauna/flora between lithofacies

The main differences in the diversity of organisms between lithofacies appears to depend on the presence or absence of Retilamina. It is totally absent from both the Dolomitic Moundstone (BD-1) and rare in the Nodular Moundstone (BN-1), hence, none of the coelobitic organisms associated with Retilamina are present in these lithofacies. In addition, calcareous algae are completely absent from outside cavities in the Dolomitic and Nodular Moundstones.

Apart from the presence and absence of retilaminiform archaeocyathids and calcareous algae, and the variation in archaeocyathid morphology (see Autecology: archaeocyathids), there is little difference in the structure of the mounds in terms of organisms (see Table IV).

As regards diversity and abundance of organisms, it would appear that the Red Moundstone (BR-1) represented the optimum conditions for mound development with every organism present except Salterella.

CHAPTER VI: SUMMARY AND CONCLUSIONS

This study concentrated on a 15-20 m thick archaeocyathid-bearing biostrome complex in the Lower Cambrian Forteau Formation of southern Labrador. The Forteau Formation marks the first occurrence of carbonate in the development of the Lower Paleozoic stable continental margin, later destroyed by westward transported ophiolite complexes. The Forteau Formation overlies the sandstones of the Bradore Formation which rest unconformably on Precambrian basement. Two archaeocyathid horizons occur in the Forteau Formation: a lower 'patch reef series', and an upper 'biostrome complex.' The purpose of this study was to document the facies distribution, stratigraphy, sedimentology, diagenesis, and paleoecology of the biostrome complex.

Reconnaissance mapping and subsequent detailed analysis of eight selected areas revealed that the biostrome complex of the Forteau Formation can be divided into two laterally distinct facies; the Oolite Sand Facies, and the Biostrome Facies. Stratigraphical and sedimentological evidence suggests that the Biostrome Facies was deposited seaward of the Oolite Sand Facies with the paleoslope trending to the south or south-east. The contact between the two facies is highly irregular and indicates that there were salients and recesses in the Oolite Sand Facies with the Biostrome Facies occupying shallow swales in the recesses. Lateral shifting of facies is partly responsible for the complex lithofacies mosaic which makes any paleoenvironmental

reconstruction a simplification of the true paleogeography.

The Oolite Sand Facies consists of seven lithologies; skeletal grainstone, oolitic grainstone, mixed oolitic grainstone, mixed peloid packstone, mixed oncologic grainstone; intraclast grainstone, and dolostone and dolomitic siltstone. These lithologies can be attributed to an origin within an oolite shoal complex comparable with modern day environments (Persian Gulf, Bahamas). The active oolite shoal consisted of cross-bedded oolitic grainstones which formed in a high-energy, inter-tidal or shallow sub-tidal environment. Mixed oncologic grainstones accumulated in stable sand channels between shoals. Supratidal dolomite developed on subaerially exposed areas on top of shoals. Dolomitic siltstones and intraclast grainstone are interpreted as storm deposits in a usually subaerial environment on top of the shoals. Skeletal grainstones occurred in a well-aerated, shallow subtidal environment seaward of the active shoal. Ooids from the active shoal were transported into quieter areas behind the shoal and accumulated as shoal spillover forming mixed oolitic grainstones adjacent to the shoal with mixed peloid packstones further away.

The Biostrome Facies was deposited seaward of the Oolite Sand Facies and consists of five distinct units; Dolomite Mound Unit (BD), Red Mound Unit (BR), Nodular Mound Unit (BN), Oolite Bioherm Unit (BB), and Grey Mound Unit (BG). For the most part, the five units consist of

two laterally equivalent lithofacies; moundstone and skeletal calcarenite. Moundstone is a new, non-genetic rock-type defined as an autochthonous assemblage of skeletons and matrix sediment (commonly mudstone) of uncertain origin, which occurs as mounds or bioherms.

In the rocks under study the skeletal components of the moundstone lithofacies are: common archaeocyathids, lesser amounts of brachiopods, trilobites, and hyolithids. Calcareous algae are sometimes very common. The moundstones form mounds, biostromes or bioherms of considerable lateral extent (tens of metres) but which had sea-floor relief of only 1 or 2 metres. The mounds are flanked by the second major lithofacies; skeletal calcarenite, which drapes off the mound at angles of up to 15 degrees. The calcarenite is essentially a skeletal packstone consisting mostly of echinoderm plates which show no signs of wear, unbroken, disarticulated brachiopod valves, with lesser amounts of trilobites and hyolithids. This fauna indicates a shallow, low-energy, sub-tidal environment. The skeletal calcarenite does not vary between the five units, but five different moundstone lithofacies are recognised which can be interpreted as forming in different environments.

Dolomitic Moundstone (BD-1) and Nodular Moundstone (BN-1) are both flanked by skeletal calcarenites and are devoid of calcareous algae. They formed low, but extensive (tens of metres) mounds or biostromes in relatively deep water. They were deposited seaward of the Red Moundstone

lithofacies (BR-1) which formed smaller mounds in shallow water, flanked by Skeletal Calcareenites (BR-2) and in lateral contact with the active oolite shoal. This well-aerated, moderately high-energy environment supported a fauna and flora of high diversity. Sediments of the Grey Mound Unit (BG) and Oolite Bioherm Unit (BB) accumulated on protected, low energy swales between oolite shoals. For the most part, the Grey Moundstone lithofacies (BG-1) formed low but extensive (tens of metres) mounds, flanked by skeletal calcarenite (BG-2), deposited on a shallow swale in a relatively quiet-water environment in lateral contact with the oolite shoal spillover. Stromatolites, interbedded within the unit suggest that at times, the Grey Mound Unit was deposited in an inter-tidal environment. Small (less than 10 m) Archaeocyathid Bioherms (BB-2) are internally similar to the Red Moundstone lithofacies (BR-1) but form discrete bioherms flanked by 'quiet-water' Oolitic Calcareenites (BB-1). These lithofacies were also deposited on shallow swales, but probably in a protected environment adjacent to an active oolite shoal.

The diagenesis of the moundstones versus calcarenites was documented and discussed in terms of process, fabric and history. Several processes have modified the original depositional texture. These include bioerosion, dissolution and cementation, neomorphism, dolomitization, silicification, pressure solution (stylolitization), and fracturing. These processes are attributed to several diagenetic environments

including; submarine, a zone of mixing between meteoric phreatic and marine phreatic waters, vadose, phreatic, and a late, unspecified environment.

The two most important processes operating in the submarine environment were bioerosion and early cementation. Bioerosion was not extensive and consists of microborings (forming micritic envelopes and peloids, etc.) in calcarenites, and macroborings (ichnogenus, Trypanites) in some of the moundstones. Early submarine cementation, in the form of lithification of micrite in moundstone, and cloudy fibrous rim-cement which is facies specific (occurring only in the moundstones and not in the flanking calcarenites) is common. A radial fibrous/bladed rim-cement, which occurs in oolitic grainstones, may also be of submarine origin.

Selective, early dolomitization of muds (now dolomite) pods within the Dolomitic Moundstone lithofacies) and of bioturbation features in calcarenites occurred due to initial sediment heterogeneity in a zone of mixing between meteoric phreatic and marine phreatic waters.

Minor dissolution of aragonitic shells and considerable rim-cementation, including extensive syntaxial cements on echinoderm plates, occurred in the vadose diagenetic environment.

Diagenetic processes in the phreatic environment include fracturing, dissolution, cementation, neomorphism, and pressure solution (stylolitization). Calcium

carbonate released during extensive stylolitization was the source of iron-rich cement which occluded pores and filled fractures. A transitional neomorphic fabric, micrite-microspar-pseudospar, is interpreted to be the result of two events, or pulses of wet boundary migration of a solution film.

Late diagenetic events include; extensive dolomitization which often obscures earlier dolomite fabrics, rare silicification, and rare stylolitization.

Certain aspects of the paleoecology of the Biostrome Facies were investigated using field and laboratory techniques. The autecology of archaeocyathids, calcareous algae, stromatolites, a new, primitive 'coelenterate', brachiopods, trilobites, hyolithids, echinoderms, and agmata (Salterella) is reviewed and discussed as to the role of the organism in the biostrome. The synecology of three distinct faunal/floral assemblages are documented using trophic grouping and the function of the organism in the assemblage to describe the structure of the assemblage.

The mound flanking "skeletal calcarenite assemblage" has a very simple structure dominated by suspension feeders (echinoderms and brachiopods) with minor occurrences of deposit feeders (trilobites, hyolithids, and Salterella).

The "mound dwelling assemblage" has a more complex structure consisting of; primary producers (calcareous algae and non-skeletal stromatolites), dominated by suspension feeders (particularly archaeocyathids with lesser occurrences

of 'coelenterate', brachiopods, and rare sponges), with less significant occurrences of deposit feeders (trilobites and hyolithids).

The "coelöbite (cavity dwelling) assemblage" occurs in cavities within the moundstone. The cavities are mostly formed by the dome-shaped archaeocyathid Retilamina amourensis which may also contribute to the structure of the assemblage. A diverse biota either encrusts the cavity roof, or occurs on, or within internal sediment. Primary producers (calcareous algae; including Bija, if an algae) dominate the biota and occur as encrusters. Suspension feeders (Foraminifera, encrusting archaeocyathids, Archaeotrypa, and sponges) are common as are deposit feeders (trilobites and worms) which occur on or within internal sediment.

Vertical zonation occurs in the Red Moundstone lithofacies (BR-1) and is best defined as "a recolonization process leading to diversification".

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APPENDICES

INTRODUCTION

Appendices A to H document the vertical successions and lateral relationships of the areas studied in detail (see CH. II). The areas are documented in geographical order from west to east (Fig. 8), and the facies to which they belong are noted in the heading. Stratigraphic sections are included (where possible) for each area. The symbols used are the same for each section and a key is given in Figures 62 and 63. The sections are discussed in Chapter III of the text.

Appendix I is a detailed account of the history of archaeocyathid research and the present world distribution of archaeocyathids and associated reefs.

CARBONATE ROCKS

1. Allochthonous



Packestone



Grainstone



Silty limestone-calcareous siltstones

2. Autochthonous



Moundstone



Boundstone

3. Dolomite



Dolostone



Dolomitic limestone



Silty dolomite-dolomitic siltstone

SILICICLASTIC ROCKS



Sandstone



Siltstone



Silty shale



Shale

PODS AND LENSES



Dolomite pod



Skeletal calcarenite lens



Siltstone lens

Fig. 62: Key to lithologies used in section figures.

SKELETAL COMPONENTS

▽ Archaeocyathids (cups)

∩ Retilamina

△ Calcareous algae

• ~ Girvanella

⌒ Stomatolites

↖ Coelenterate

▽ Brachiopods

⌒ Trilobites

△ Hyolithids

○ Echinoderms

▷ Salterella

BIOGENIC STRUCTURES

⊢ Macroborings (Trypanites)

U^o Burrows (D=Dolomitized)

~ Tracks and trails

NON-SKELETAL COMPONENTS

○ Ooids

◐ Oncolites

• Peloids

◐ Intraclasts

• Grapestones

• Quartz silt

SEDIMENTARY STRUCTURES

≡ Cross-bedding

≡ Minor cross-bedding

~ Symmetrical ripples

~ Asymmetrical ripples

~ Interference ripples

f Graded bedding

√ Stylolites (N=nodular)

Fig. 63: Key to symbols of components and structures used in section figures.

APPENDIX A

Blanc Sablon (Biostrome Facies)

This outcrop is located 3.5 km north of Blanc Sablon (Fig. 8) where it forms a conspicuous topographic feature rising to a height of 461 ft. (150 m) above a flat tract of land consisting mostly of lowermost Forteau Formation. This butte is the western-most outcrop studied. Outcrop is restricted, however, to the south side of the hill and to the very top where exposures of moundstone form twin peaks, separated by recessive weathering calcarenite. In all, approximately 7.0 m of continuous vertical exposure can be regarded as Biostrome Facies. Lateral exposure is relatively poor, extending for not more than 20.0 m along any one horizon.

At the base of the Biostrome Facies siltstone is transitional and laterally equivalent to skeletal calcarenite (Fig. 64). About 0.50 m higher in the sequence, part of this calcarenite is replaced by archaeocyathid moundstone while the part of the calcarenite adjacent to the siltstone persists.

The siltstone lithofacies is 1.45 m thick, is slightly calcareous and contains an abundant ichnofauna with vertical burrows and numerous horizontal tracks and trails. The siltstone is laminated throughout and often ripple-marked. Asymmetrical ripple-marks are aligned along 025° and indicate a current direction toward the north-west (295°). Asymmetrical interference ripples occur with a wavelength for the major ripples of 9.5 cm and an amplitude of 1.2 cm. These major ripples trend 310° while the minor ripples trend 027°. This siltstone is identical to, and can be regarded as a continuation of, the open-shelf facies of the Lower Forteau Formation.

The siltstone passes laterally and is transitional into skeletal calcarenite (BG-3) which is often very coarse-grained, especially close to the moundstone contact where archaeocyathid fragments are common. The majority of the skeletal debris is echinoderm, but convex-up, disarticulated, inarticulate brachiopod shells, often leached, are also common. This calcarenite, best described as a truncated wedge, has a maximum thickness of 0.82 m and a lateral extent of 1.60 m. The contact with the moundstone is not well exposed but is interdigitatory. The calcarenite drapes off the moundstone at angles up to 15°. Minor cross-bedding, always dipping away from the moundstone, occurs in the draping calcarenites.

Diffuse ripples occur at the very top of the calcarenite.

Laterally equivalent Grey Moundstone lithofacies (BG-1) lies directly on the calcarenite. Of the archaeocythids, stick-forms dominate over narrow, thick-walled cones by a ratio of 2:1-3:1. Calcareous algae is abundant. The maximum thickness of the unit is 3.1 m, and within this unit, the density of archaeocythids differs greatly. Archaeocythids increase in density from the base towards the middle of the unit and become rare towards the top where only the occasional "colony" of stick-forms (Archaeocyathus) is present along with abundant, small, digitate, non-skeletal stromatolites (SH-V type of Logan et al., 1964). Inarticulate brachiopods are present where archaeocythids occur. Stylolites are present but not as abundant as in other units.

The moundstone sequence is laterally persistent except for a "channel-like" body of calcarenite. This body is 7.60 m wide and 1.60 m thick with a horizontal top and a convex base and thins laterally both ways from a maximum thickness in the centre. The calcarenite is graded, from a very coarse skeletal grainstone at the base upwards into packstone and wackestone, and into skeletal siltstone at the top where laminations and minor cross-bedding occur. The base and sides of the unit in contact with moundstone is covered.

Conformably overlying the Grey Mound Unit but with a distinct contact are rocks of the Red Moundstone lithofacies (BR-1). This bed is laterally persistent, averages 1.30 m thick, and has a stylonodular appearance. Small lenses of calcarenite occur within the moundstone. Upright archaeocythids are abundant with stick forms (Archaeocyathus) and thinner-walled, low-angle cones (Metaldetes) being present in equal amounts. Retilamina, associated with calcareous algae is common and inarticulate brachiopods are present throughout. Echinoderm debris is also common throughout the lithofacies.

Overlying the Red Moundstone lithofacies is the Grey Mound Unit again with a thickness of 1.90 m. The unit begins with a thin (.08 m) mudstone layer which grades upward into a very stylolitized mudstone (0.10 m thick), almost stylolaminated, with well defined clay stylocumulates. The bulk of the unit consists of grey algal/archaeocythid moundstone. Thin-walled, low-angle cones (Metaldetes) are the most common, out-numbering Archaeocyathus but Retilamina is also common. The cones become slightly

larger towards the top. Calcareous algae is abundant. The moundstone forms the two peaks at the top of the hill, separated by a tabular lens of skeletal calcarenite which extends for 40-50 m. Contacts between moundstone and calcarenite are straight but interdigitatory. A thicker unit of calcarenite (1.60 m) is partially exposed to the south-west of the main summit. No draping occurs in the calcarenites.

APPENDIX B

Diversion Reef (Oolite Sand Facies and Biostrome Facies transition)

This section in the Oolite facies is poorly exposed along a track over a distance of some 0.8 kms, situated approximately 4 kms to the north of L'Anse-au-Clair (Fig.8). Because of the undulating nature of the topography in this area, no continuous vertical section can be measured but an approximate composite cross-section, consisting of 5 vertical sections can be compiled (Fig.65).

The transition from the Biostrome Facies to the Oolite Sand Facies is not as sharply delineated as at Osprey Reef (Appendix C) but occurs gradually. Skeletal calcarenites (grainstones) of the Oolite Sand Facies consisting predominantly of Salterella cones, echinoderm plates, trilobite debris, and inarticulate brachiopods, both overlie and are in lateral contact with the Grey Mound Unit (BG) of the Biostrome Facies. The Oolite Sand Facies replaces the Biostrome Facies northwards (section a, b, c; Fig.65).

Section c (Fig.65) begins with a small outcrop of the archaocyathidrich Grey Moundstone lithofacies (BG-1) followed by a covered interval of 1.58 m. The next exposure consists of Salterella-rich skeletal grainstone (2.22 m) which passes upwards into 0.23 m of burrowed, oolitic, skeletal grainstone. The burrows are dolomitized and the skeletal fraction consists of abundant Salterella cones and echinoderm plates along with trilobites and inarticulate brachiopods. A covered interval of 0.44 m is succeeded by a light-to dark-grey, burrowed (dolomitized), skeletal grainstone with abundant Salterella and echinoderm plates along with minor amounts of trilobite debris, hyolithids, silt-grade quartz, ooids, and coated (Girvanella) grains. The thickness of this unit is 0.93 m. Another covered interval (1.65 m) is followed by 1.3 m of burrowed, oncolitic, skeletal grainstone. The oncolites, consisting of Girvanella tubules, have a maximum size of 3 cm and occur with minor amounts of silt-grade quartz, peloids, and ooids. The skeletal fraction (40% of total rock-volume) consists of Salterella cones, hyolithids, echinoderm plates, and trilobites.

Section d (Fig.65) commences with shales and calcareous silts rich in trace-fossils, characteristic of the lower part of the Forteau Formation open-shelf facies (James and Kobluk, 1978), and is apparently laterally equivalent to the Biostrome Facies exposed to the south (section c, Fig.65). This implies that the lower part of the Forteau Formation is much thicker to the north and consequently

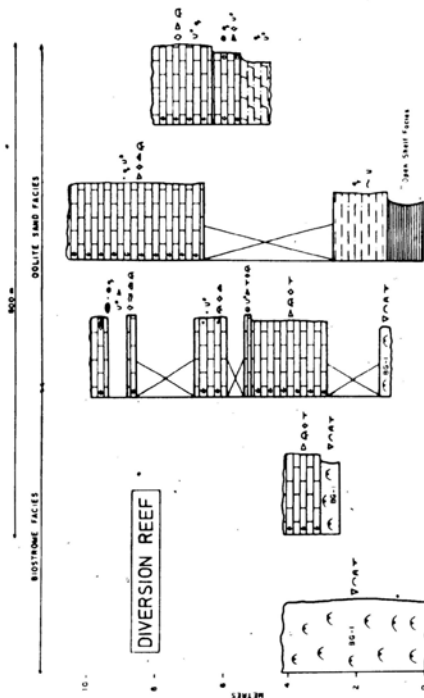


FIG. 65: Stratigraphic sections in the Blostrone Facies - Oolite Sand Facies transition at Diversion Reef.

the Oolite Sand Facies must thin northwards. The base of the Oolite Sand Facies is taken here as a 1.6 m exposure of calcareous siltstone with numerous tracks, trails, and burrows, which conformably overlies the shales. This lithotype is taken as the base of the Oolite Sand Facies as it is often seen as the basal member of the Biostrome Facies elsewhere (Blanc Sablon, L'Anse Amour, and Fox Cove). A covered interval of 3.78 m is followed by 3.82 m of burrowed, skeletal grainstones consisting of Salterella cones and echinoderm plates with subordinate elements of hyolithids and trilobites. These are the highest beds seen.

The northermost section outcrops in a small cliff (3.27 m) and is equivalent in part to the top of the covered unit and base of the skeletal grainstone in section d (see section e, Fig.65). The basal lithology (0.90 m) is burrowed dolomitic siltstone with a minor skeletal fraction (less than 10%) of echinoderm plates, trilobites, and rare Salterella cones. This is overlain by 0.77 m of oolitic grainstone containing less than 15% echinoderm plates and Salterella cones, plus a minor silt fraction. The ooids are dolomitized. The sequence terminates with 1.6 m of burrowed skeletal grainstones, again, dominated by echinoderm plates, Salterella cones, trilobites, and minor occurrences of silt and coated grains.

APPENDIX C

Osprey Reef (Oolite Sand Facies and Biostrome Facies transition)

This outcrop is situated approximately 4 km to the north-east of L'Anse-au-Clair (pos. c, Fig.8) where the rocks are exposed almost continually in a lateral section extending for 800 m. The biostromal complex of the Porteau Formation is here faulted against the lower patch-reef series of the Porteau Formation. This is an important section because it demonstrates the lateral relationship between the two major facies; the Biostrome Facies and the Oolite Sand Facies (Figs. 66 and 73).

The Biostrome Facies here is essentially a complex of two distinct lithofacies; Red Moundstone (BR-1) and Skeletal Calcarenite (BR-2) which are exposed in outcrop at the ratio of 2:3, respectively. Lateral and vertical changes in lithofacies are extremely rapid, occurring over a few metres. The macro-relationships are shown diagrammatically in Fig.73 (in pocket), compiled from a photo-mosaic and field sketches. Field observations were restricted due to the inaccessibility of much of the exposure. The section is described from south-west to north-east.

To the south-west (section a on Figs. 66 and 73), the section is predominantly a very coarse-grained skeletal calcarenite with a thinly-bedded gainstone with a matrix of archaeocyathids brachiopods, trilobites, and echinoderm, debris. Vertically, the calcarenite becomes more massively bedded but still retains its coarse-grained character. At 6.15 m from the base of the section is a thin (9 cm) band of calcareous siltstone with symmetrical ripple marks. This siltstone is in turn overlain by coarse-grained skeletal calcarenite. The total exposed sequence is 8.0 m thick.

Further to the north-east (section 2), skeletal calcarenite both overlies and passes laterally into Red Moundstone (BR-1). The skeletal calcarenite is interrupted again by another, laterally impersistent calcareous silt bed about 1.0 m wide and 8 cm thick at the maximum, tapering both ways to the stylocumulate of a stylolite. The siltstone contains asymmetrical ripples with a wavelength of 50 mm and amplitude of 6 mm.

The sequence at section 3 is dominated by the typical Red Moundstone lithofacies. Archaeocyathids are very abundant with low-angle cones (Metaldetes) outnumbering

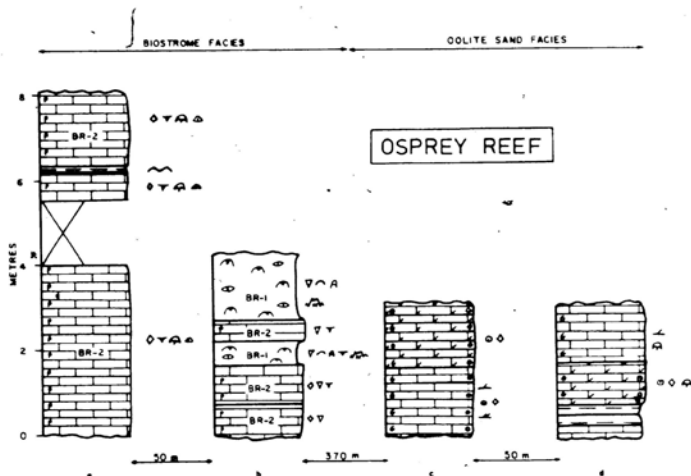


Fig. 66: Stratigraphic sections in the Biostrome Facies - Oolite Sand Facies transition at Osprey Reef.

sticks (Archaeocyathus) by 2:1; Retilamina is common, as are brachiopods. The moundstone has a stylonodular appearance due to intense stylolitization. Contact with the surrounding calcarenite is both straight and sharp, draping (39° towards 140°), and interdigitatory. Small lenses of calcarenite, averaging 20 cm x 7 cm (maximum 48 cm x 15 cm), occur within the moundstone but make up less than 10% of the lithofacies.

Laterally equivalent to the moundstone is a thick (5 m) sequence of homogenous skeletal calcarenite (section 5) which extends laterally for about 21 m before a contact with moundstone (section 6). The contact between the moundstone and calcarenite is straight but interdigitatory. Within the moundstone are thin (up to 20 cm), persistent (10.0 m) sheets of calcarenite. Wherever these sheets occur, the overlying moundstone is "recolonised" by a thin (25 cm) bed with numerous retilaminiform (Retilamina) archaeocyathids in a grey to green to red mudstone matrix with characteristic pendent calcareous algae growing on the underside of each archaeocyathid. Retilamina skeletons are all orientated convex-up, rarely touch each other, but occur in profusion stacked close to each other. Coarsely crystalline cement (pink) fills in the cavity between the calcareous algae which grows on the underside of Retilamina and internal sediment. Other fauna associated with Retilamina is rare, although stick-form archaeocyathids (Archaeocyathus) occasionally occur. A rapid transition occurs vertically into the normal Red Moundstone where cones (Metalletes) and sticks (Archaeocyathus) are abundant and Retilamina subordinate.

The same "recolonization" process is seen again (section 7) on top of an erosive channel of skeletal calcarenite. This channel has a horizontal upper surface but a very irregular bottom surface with relief varying by as much as 10 cm. Consequently the thickness of the body varies between 25 cm and 35 cm. It is overlain by the retilaminiform moundstone assemblage followed by typical Red Moundstone.

To the north-east of section 7, two normal faults of small displacement occur and outcrop becomes sparse. Rocks of the same unit, however, are picked up again (section 8) where Red Moundstone and skeletal calcarenite are seen laterally juxtaposed in small exposures.

One small exposure (section 9) represents the last time that the Red Moundstone is seen along this section, the remainder of the outcrop is formed of rocks of the Oolite

Sand Facies. The outcrop consists of both Red Moundstone and oolitic grainstone which are seen to grade on to the other. The Red Moundstone consists of three times as many stick-forms as cones and reticulaminifera. A considerable number of the cups are toppled. Ooids can be seen in abundance in the moundstone matrix which also contains a lot of skeletal debris. A lot of skeletal debris, including archaeocyathid cups, also occurs in the adjacent oolitic grainstone, which along with skeletal calcarenites, makes up the remainder of the section, to the north-east.

Two small sections were measured in the Oolite Sand Facies (sections c and d on Figs. 66 and 73). Section c is located within 20 m of the contact with the biostrome and section d is located approximately 50 m to the north-east of section c.

Section c (total thickness 3.10 m) consists entirely of rocks of the Oolite Sand Facies. The basal 86 cm consists of light-grey, orange-speckled, cross-bedded, partially dolomitized, oolitic grainstones. All the ooids are dolomitized and there is also partial dolomitization of the matrix. It is overlain by a light-grey, cross-bedded, oolitic grainstone (74 cm) with a minor trilobite fraction and dolomitized ooids. The topmost unit is a light-grey oolitic grainstone (1.50 m) with a relatively high skeletal content consisting predominantly of echinoderm plates. The ooids are again dolomitized, but no cross-bedding occurs.

Section d (total thickness 2.94 m) consists of burrowed dolostones, skeletal, oolitic grainstones, and skeletal grainstones. The lowermost exposed beds consist of 66 cm of burrowed dolostones with a small silt fraction, apparently restricted to the burrows. This unit is interrupted by a thin (6 cm) bed of horizontally laminated dolomitic siltstone consisting of equal proportions of finely crystalline dolomite and sub-angular to sub-rounded silt-grade quartz. This bed occurs at 0.45 m from the base of the section.

The dolostones are overlain by 1.08 m of cross-bedded, light-grey oolitic grainstones with varying amounts of skeletal material and peloids. Towards the base of this bed dolomitized ooids and peloids occur in equal proportions with a relatively small (less than 15%) skeletal fraction consisting of echinoderm plates, inarticulate brachiopods, and trilobites. The peloid fraction disappears upwards

replaced by partially dolomitized ooids and a skeletal fraction (20%) of echinoderm plates, brachiopods, and trilobites. .

The oolites are overlain by a partially dolomitized (mottled, 20% of volume), cream to pink, skeletal grainstone consisting predominantly of echinoderm plates with minor quantities of trilobites and brachiopods. This grades into a skeletal grainstone with minor dolomitization (less than 10%) and a 15% fraction of dolomitized ooids. The combined thickness of the skeletal grainstones, the highest beds exposed, is 1.20 m.

A rose diagram of 17 measurements of cross-bedding current direction taken from the oolites (Fig.23) indicates a widespread polymodal current direction. This result may be due to insufficient data.

APPENDIX D

Forteau (Oolite Sand Facies)

The thickest measured section (18.5 m) in the Oolite Sand Facies occurs in poorly exposed outcrops along the main road about 1 km to the east of Forteau, and in small quarries adjacent to a track heading southwards off the main road (position d, Fig.8).

A complete section of the Forteau Formation from the contact with the Bradore Formation to the present day level of erosion can be measured. The base of the Oolite Sand Facies is taken at the conformable contact between platy limestone and shale beds, characteristic of the lower part of the Forteau Formation and a skeletal calcarenite characteristic of the upper part of the Forteau Formation in Labrador (Fig.67).

The basal calcarenite (1.6 m) is partially dolomitized (mottled, totaling 20% of total rock volume), burrowed, dark-grey, skeletal grainstone consisting of worn and broken fragments of echinoderm plates, Salterella cones, and trilobite debris, along with a 10% silt fraction.

This is overlain by a dark grey, intraclast grainstone (4.0 m) consisting entirely of intraclasts cemented together by coarsely crystalline pink calcite which makes up 40% of the rock volume. The intraclasts are stretched-out or rounded 'rip-up' clasts consisting entirely of tubules of the blue-green algae Girvanella. At the base, the clasts are elongated with ragged margins but higher up the clasts are more rounded.

This passes vertically into a poorly-sorted, dolomite-mottled, oncolitic-oolitic grainstone (1.2 m) with a skeletal fraction consisting of Salterella cones, echinoderm plates, and minor occurrences of hyolithids and trilobites. The oncolites consist of a nucleus of composite grains, ooids, or skeletal fragments surrounded by tubules of Girvanella and are up to 3 cm long.

The oncolitic grainstone is succeeded by a dark grey skeletal grainstone (2.0 m) with brown-orange mottles (dolomite). The grainstone consists mainly of echinoderm plates and trilobite carapaces and the occasional hyolithid cone and brachiopod valve.

The grainstone is overlain by a light-grey to light-brown dolostone with a minor skeletal fraction of abraded

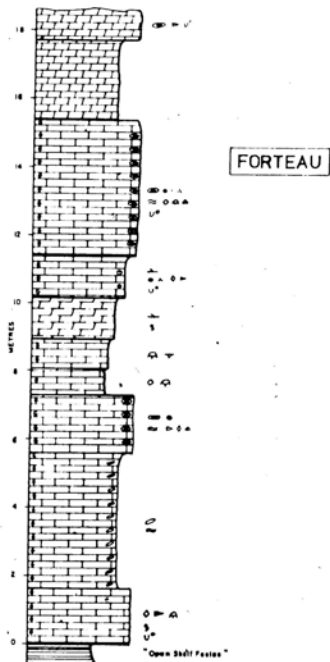


Fig. 67: Stratigraphic section in the Oolite Sand Facies at Forteau.

trilobites and brachiopods. This grades vertically into a ripple-laminated dolomitic siltstone with some burrows. Altogether, this unit is 1 m thick.

Overlying the dolomite beds is a 1 m thick bed of burrowed (dolomitized), dark-grey, oolitic grainstone with a minor (less than 10%) skeletal fraction of echinoderm plates and Salterella cones.

Following the oolite is a relatively thick (4 m) sequence of black to dark-brown oncolitic and oolitic grainstones. Oncolites, up to 2.5 cm across and consisting of Girvanella tubules, occur in a matrix of ooids, peloids, composite grains, echinoderm plates, trilobite debris, and hyolithids.

The top of the exposed sequence consists of 3.5 m of burrowed dolostone, often with dolomitized oncolites and with a skeletal fraction of less than 5%.

APPENDIX E

L'Anse Amour (Biostrome Facies)

The largest continuous outcrop of the Biostrome Facies is found in a cliff-section to the south-west of the Pointe Amour Peninsula (position E, fig.8). This cliff is found about 50 m inland from the high-tide level and is in excess of 35 m high. The vertical exposure totals some 15 m and forms the brow of the cliff which extends laterally for 2.25 km. Several minor faults cross the cliff but the displacement is small. Although the land surface rises gently inland from the cliff-section, the strata is repeated by faulting so the most complete section is seen in the cliff itself. Four sections were measured along the length of the outcrop (Fig.68).

The contact with the open-shelf facies of the Forneau Formation is seen only at the southern end of the cliff. Dolomitic Moundstone (BD-1) is in direct contact with shales and siltstones of the open-shelf facies and the moundstone fauna here consists of large, high-angle cones and bowl-shape archaeocyathids (Metaldetes). Moundstone grades laterally into skeletal calcarenite which in turn grades laterally into a rippled calcareous siltstone and then back into skeletal calcarenite. The calcarenite is a skeletal grainstone with small archaeocythid fragments, brachiopods, and trilobites; is less than 20 cm thick and extends laterally for 75 cm from the moundstone to the siltstone. It passes both laterally and vertically into rippled-laminated calcareous siltstone (the ripples are asymmetrical, with a wavelength of 10 cm and an indicated current direction towards 164°). The vertical extent of the siltstone varies between 10 cm adjacent to the moundstone and 25 cm away from it. Above the siltstone, adjacent to the mound is 40 cm of skeletal calcarenite which drapes off the moundstone at angles of less than 10°. The calcarenite is replaced vertically by moundstone.

The most complete section at L'Anse Amour occurs about 250 m from the southern end of the cliff. The basal division consists of 2.2 m of Dolomitic Moundstone (base not seen in measured section) which is at least in part equivalent to the shales and siltstones to the south. The moundstone is typically dark grey or green, archaeocyathid-rich with a mudstone matrix (lithofacies BD-1). No large dolomite pods are seen although small patches of dolomitization occur along with small lenses of skeletal calcarenite. Weathering obscures much of the detail although a certain vertical zonation of fauna is apparent.

Towards the base, narrow cone archaeocyathids (*Metaldetes*) dominate with only the occasional isolated stick-form (*Archaeocyathus*). In the top 0.35 m, clumps of branching stick-forms occur which are evenly spaced (c. 0.35 m apart) and are associated with scattered coelenterate fronds.

Overlying the Dolomitic Moundstone lithofacies (BD-1) is the thinnest and least persistent unit consisting of Red Moundstone (BR-1). The thickness is 1.20 m in the measured section but is often less and rarely more than that figure. This unit is characterized by the deep red colour of the mudstone matrix, the stylonodular appearance, and abundance of upright archaeocyathids. Narrow cones dominate the archaeocyathids fauna with stick-forms and reticulaminiforms also playing an important role. Calcareous algae is common throughout the units, coelenterate fronds occur locally; and inarticulate brachiopods are common. Small lenses of skeletal calcarenite make up less than 10% of the rock by volume.

The main part of the outcrop consists of Nodular Moundstone (BN-1). This unit averages 6 m thick and consists of badly weathered, rubbly, black to dark grey, nodular moundstone with a mudstone to wackestone matrix. Small lenses of skeletal calcarenite and small isolated patches of shale occur within the moundstone. Archaeocyathid density is low but consists primarily of narrow and wide cones (*Metaldetes*). Brachiopods are rare. The unit is laterally persistent and occurs in sections measured 2 km away to the north. Within the L'Anse Amour area (and at Fox Cove) the Nodular Mound Unit (BN) is terminated by a planar erosion-surface contact with oolitic and skeletal grainstones (Unit BB).

Within all three units (BD, BR, BN) exposed below the erosion surface, large accumulations of skeletal calcarenite occur as wedges which flank the moundstone. In the area between the settlement of L'Anse Amour and the southern extent of the cliff (about 1.0 km) there are six such wedges which vary in size from 1.5 m to 4.5 m thick by 2.5 m to 28 m long at the base (maximum extent). In all six occurrences, calcarenite drapes off the moundstone at angles between 11° and 18° , and in directions between 013° and 050° . Minor cross-bedding is often seen on the inclined beds, always dipping away from the mounds. Four of the wedges are adjacent to the nodular moundstone (BN-1), one is adjacent to the Red Moundstone (BR-1), and one, the largest, is adjacent to all three lithofacies (BD-1, BR-1, and BN-1). The largest wedge (size 4.5 m by 28 m) occurs at the southern end of the cliff. This

wedge consists of skeletal packestone to grainstone with several beds, up to 20 cm thick, consisting solely of unbroken brachiopod valves. These brachiopod-rich beds dip gently off the mound (less than 10°) but are horizontal within 25 cm from the mound. The contact between the moundstones and calcarenite interdigitates over 50 cm. At the top of the wedge is a large symmetrical megaripple with a wavelength of 1.85 m and an amplitude of 16 cm. Current directions could not be measured. It is directly underlain by a 4 cm thick bed with slightly asymmetrical ripples (wavelength of 10 cm).

Overlying the Nodular Mound Unit (BN) and separated by a planar erosion surface described above is another 5.56 m of section, divisible into 2 units (BB and BG). The Oolite Bioherm Unit (BB) lies on top of the erosion surface and has a maximum thickness of 3.05 m. At the south end of the cliff, coarse skeletal calcarenite (BB-3) with a thickness of 27 cm occurs at the base and passes vertically into skeletal oolitic calcarenite (BB-1) more than 2 m thick, with no sedimentary structures. A small archaeocyathid-rich moundstone occurs as a Bioherm (BB-2) of unknown lateral dimensions (probably less than 1.50 m) and 0.40 m thick.

About 250 m to the north a coarse, skeletal, oolitic grainstone (occasionally floatstone) is at the base (thickness 32 cm) and contains large archaeocyathid cups, echinoderm fragments, brachiopods, and trilobites as well as asymmetric ooids. This grades upwards into an oolitic packestone (48 cm thick), in which the ooids are selectively dolomitized. Above the dolomitized oolite bed is a very clean, light-grey oolitic packestone (6 cm thick) with very little skeletal material which truncates the dolomitized ooids underneath. The light-grey ooids are in turn, truncated by 15 cm of very coarse skeletal oolitic packstones (BB-1). Both erosive contacts are planar, distinct lines but only occur locally.

The next horizon of oolitic packstones (95 cm) contains another small bioherm of unknown, but restricted dimensions. This bioherm has a flat lower surface and a strongly convex upper surface with the top truncated by the overlying unit. The bioherm, in the same level as the one to the south and of another 1 km to the north, consists of a red to grey archaeocyathid moundstone in a mudstone to packestone matrix. Stick-form archaeocyathids outnumber cones by 2:1; reticulaminiforms are common; trilobites, brachiopods, and calcareous algae are present. The largest bioherm is the one to the north which has a maximum height

of 1.60 m at the central point of the structure and is 5 m wide at the base. The contact between the bioherm and the oolites is straight although interdigitatory.

Two kilometres to the north of L'Anse Amour, equivalent beds consists of 1.15 m of skeletal packstone to grainstone overlain by 1.60 m of coarse, but fining upwards skeletal oolitic calcarenites.

The highest beds exposed overlie the Oolite Bioherm Unit (BB) and consist of rocks of the Grey Mound Unit (BG). The Grey Moundstone lithofacies (BG-1) consists of abundant clacareous algae often associated with retilaminiform archaeocyathids with cones outnumbering stick-form archaeocyathids by 2:1. The cones (Metaldetes) are large and thick-walled. Poorly exposed outcrops of laterally equivalent calcarenites occur but their geometry is unknown. About 1 km to the north of L'Anse Amour, a coarse skeletal calcarenite (80 cm thick) which grades upwards from the underlying oolitic packstone is apparently the lateral equivalent of the moundstone. One km further north, the same Grey Moundstone occurs (0.50 m thick) although the basal 0.20 m of grey mudstone appears unfossiliferous. At L'Anse Amour the grey moundstone is 2.80 m thick, but the top 0.30 m consists of skeletal (Girvanella) stromatolites (type LLM-C of Logan et al., 1964) which are the highest beds seen but are also laterally equivalent in part to the Grey Moundstone.

APPENDIX F

Fox Cove (Biostrome Facies)

The only coastal exposure of the Biostrome Facies is found at Fox Cove on the Pointé Amour peninsular (position F, Fig.8) where it is faulted against the patch-reef series of the Forteau Formation. Although less than 14 m of section is exposed vertically, about 300 m of strata is exposed laterally. The stratigraphical contact of the Biostrome Facies with the open-shelf facies of the Forteau Formation is seen only at the north-east end of Fox Cove (Figs. 69 and 70).

The sequence (see Figs. 69 and 70) commences with a thick (2.5 m) unit of massively bedded calcarenite which grades, 20 m to the south-west into calcareous siltstone with common trace fossils. Several sets of ripple-marks are associated with the siltstone including sinuous symmetrical ripples, interference ripples, and asymmetrical ripples. Current direction varies between 030° and 172°.

The skeletal calcarenite passes upward into 27 cm of well-laminated calcareous siltstone with interbedded shales containing small lenses of skeletal calcarenite. This unit is overlain by 1.20 m of massively bedded, homogenous, coarse-grained skeletal calcarenite (packstone to floatstone with packstone matrix). Archaeocyathid fragments are fairly common but most of the material consists of echinoderm plates, with brachiopods, and occasional trilobites and hyolithids. The unit terminates with a mega-rippled surface of symmetrical ripples having wavelengths of between 18 and 35 cm. Crests of the ripples trend 055°. This mega-rippled horizon is also seen 50 m to the south-west where the wavelength is 96 cm with symmetrical crests trending 049°. Three hundred metres to the south-west, near to the beach, both symmetrical mega-ripples (wavelength of 34 to 45 cm, crests trending 066°-085°) and sinuous, asymmetrical megaripples (wavelength of 15 cm, current direction 166°) occur.

Overlying the mega-rippled calcarenite is a laterally diverse suite of shales and silts (lithofacies BD-2), Skeletal Calcarenite (BD-3) and Dolomitic Moundstone (BD-1), which together attain a maximum thickness of 4.0 m. Towards the north-east, the sequence commences with 1.60 m of shales and calcareous siltstones. Shales dominate at the base but sediments become silty towards the top with occasional small ripple laminations. Rare, small lenses of skeletal calcarenite (maximum size 33 cm x 5 cm) occur within the unit.

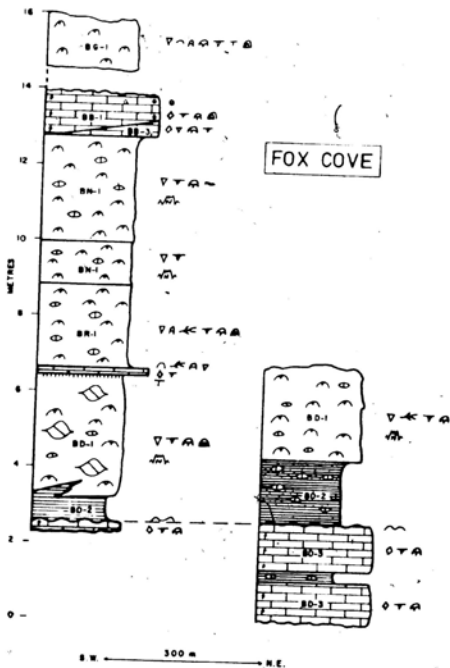


Fig. 69: Stratigraphic sections in the Biostrome Facies at Fox Cove.

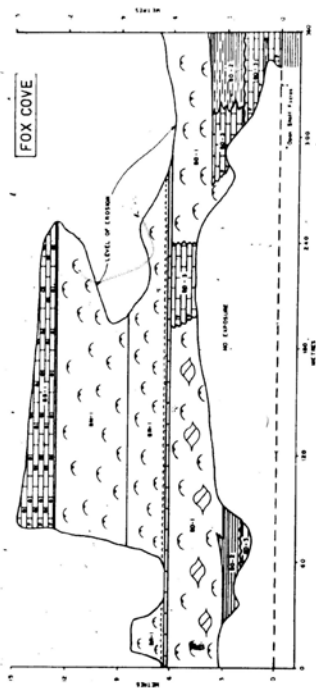


Fig. 70: Cross-section of exposed strata in the Biostrome Facies at Fox Cove illustrating unit and lithofacies relationships.

Overlying the shales with an irregular contact is the Dolomitic Moundstone (BD-1). In places, the base of the moundstone consists of toppled stick-form archaeocyathids (Archaeocyathus) in a mud/silt matrix. This grades laterally into either a purer calcareous siltstone or a brachiopod packstone with convex-up inarticulate brachiopod valves forming beds less than 15 cm thick. Most of the time, the moundstone lies directly onto the shales and silts. In this situation, very large, wide cones and bowl-shaped archaeocyathids (Metaldetes) with diameters averaging 10.5 cm dominate the fauna along with inarticulate brachiopods. Associated fauna includes large stick-form archaeocyathids and an occasional frond of coelenterate. About 1.0 m higher, however, sticks outnumber narrow cones and the coelenterate has an erratic distribution from absent to very abundant, sometimes occurring as the sole skeletal element. Branching, stick-form archaeocyathid (Archaeocyathus) "colonies" are common at this horizon and very evenly spaced 35 cm apart. Skeletal calcarenite lenses or pods and small pods of fine-grained dolomite are present but are not extensive. The top of this unit is not exposed at the north-east end of Fox Cove.

Traced to the south-west, the underlying shales (BD-2) become more silty in nature and eventually calcareous siltstone is replaced by Skeletal Calcarenite (BD-3), all within 50 m from the north-east end. Dolomitic Moundstone overlies the calcarenite. Thirty metres further to the south-west the calcarenite thins against laterally equivalent Dolomitic Moundstone (BD-1). The calcarenite drapes off the moundstone at angles of less than 10°, and has an interdigitatory contact.

The shales are seen again to overlie the mega-rippled calcarenite at the south-west end of Fox Cove, 300 m from the previously described occurrence, and on the same stratigraphical horizon. The shales here are black, featureless, almost 1 m thick and extend at least 50 m further to the south-west. They underlie the Dolomitic Moundstone in the lower part and occur as lateral equivalents in the upper part where a tongue of shale drapes off the moundstone at angles up to 30°.

The Dolomitic Moundstone to the south-west differs from that to the north-east in at least two important ways. The proportion of dolomite present and the size of the pods in which it is found is much greater to the south-west. The dolomite makes up approximately 25% of the lithofacies and is found in large pods and lenses

(maximum more than 2 m long) which are surrounded by stylonodular moundstone which because of the differential intensity of stylolitization, appears to have wrapped itself around the dolomite pod. Some pods on weathered surfaces show laminations and bioturbation features (vertical and inclined burrows). Upright archaeocyathid cups and 'relict' (?) patches of skeletal calcarenite occur occasionally. The second difference between the two areas is the absence of coelenterate in the south-west, the fauna there consisting predominantly of narrow cones (*Metalletes*) dominant over stick-forms (*Archaeocyathus*). Between the two main exposures is a lens of skeletal calcarenite (coarse-grained packstone) at least 1.40 m thick and extending laterally for 35 m. Only one contact with the moundstone is seen (south-west end) where the calcarenite thins towards and drapes off the mounds at gentle angles. Adjacent to the contact, archaeocyathid cups are seen in the calcarenite, otherwise the skeletal composition consists of echinoderms, brachiopods, or trilobites.

The Dolomite Unit (BD) at Fox Cove is brought to an abrupt end by a very thin but laterally extensive (more than 300 m) sheet of skeletal calcarenite. Two occurrences of ripples are seen in the sheet. They are both symmetrical with wavelengths ranging from 5.0 to 7.5 cm and crests of the ripples trending between 150° and 277° in one case, and 124° in the other. The contact with the underlying moundstone is planar and apparently erosional as archaeocyathids are truncated. The upper eroded surface of the moundstone is covered with numerous, small black dots which represent the apertures of macroborings, similar to those described from the lower patch-reef series (James et al., 1977) and attributed to the morphogenus *Trypanites*. These borings, now filled with sediment are seen to penetrate archaeocyathid skeletons and surrounding matrix (Fig. 31). They are absent in some places and very dense in others; up to 260 borings occurring in 10 square centimetre areas in places although the average is between 150 per 10 square centimetres (n=5).

Overlying the calcarenite sheet are isolated exposures of Red Moundstone lithofacies (BR-1). Whenever the base is exposed, the colonization assemblage documented from Osprey Reef occurs averaging 30 cm thick. This grey/green moundstone consists mainly of abundant rellaminiform archaeocyathids associated with the pendent growth-form of calcareous algae on the underside. Another significant skeletal component is the coelenterate whose fronds appear to spread out both horizontally and downwards. Occasional

stick-form archaeocyathids are also found. This unit passes transitionally upwards into more typical Red Moundstone (BR-1) where abundant, upright narrow cones are the dominant fauna, along with stick-forms; bowls are rare. Calcareous algae is common, inarticulate brachiopods are present to common while trilobites are rare. The coelenterate is locally common. The unit, of maximum thickness 2.25 m has a stylonodular appearance. Small lenses of skeletal calcarenite make up less than 10% of the volume. The corresponding skeletal calcarenite lithofacies (BR-2) does not occur at Fox Cove probably due to inadequate exposure.

Red Moundstone passes transitionally over a few centimetres into the overlying Nodular Moundstone lithofacies (BN-1) which is 3.9 m thick. Although very badly weathered, it can be discerned that there is a distinct partition between adjacent areas where archaeocyathids are common and where they are rare. They are common in areas of up to 1 - 2 m across and about 1 m high. Thick-walled archaeocyathids and funnels dominate with minor stick-forms in a mudstone matrix. Brachiopods are common. Skeletal calcarenite makes up to 50% of this unit and occurs as small lenses and elongated tubular lens (maximum size 1.0 m by 0.15 m). The composition of the calcarenite is often dominated by unbroken, inarticulate brachiopod valves.

The adjacent strata, with a sparse archaeocyathid fauna is a nodular mudstone with small, skeletal (brachiopods) calcarenite lenses (less than 10% volume) and green, limy shales (5%). Although fossils are rare, isolated archaeocyathids do occur, particularly towards the top. Branching stick-forms dominate this sparse fauna along with wide cones, funnels and bowls. Narrow cones were not observed.

The Nodular Mound Unit (BN) is truncated by a planar erosion surface and overlain by skeletal, oolitic packstones (BB-1). At the base, both skeletal grainstone containing several large trilobites (*Wanneria*) along with minor ooids; and oolitic grainstones occur. The skeletal grainstone has a maximum thickness of 60 cm and thins laterally and eventually passes into oolitic packstone. Throughout the oolite sequence exposed (1.05 m thick) there is a skeletal element present. The basal 0.65 m consists of a fining upwards sequence of ooids with a corresponding decrease in skeletal content. The base is extremely coarse-grained with several large archaeocyathid cups. The oolite sequence is interrupted by a thin, 4 cm bed of skeletal packstone which is followed by another

coarse oolitic skeletal packstone bed (8 cm) and then by a purer oolitic packstone (28 cm).

Although confused by faulting and poor exposure, the succession continues inland with further isolated exposures of oolitic packstone. In some of the oolitic packstones however, small (several centimetres) ovoid in plan, skeletal (*Girvanella*) stromatolites (LLH-S/LLH-C of Logan *et al.*, 1964) occur. Apparently overlying the oolites are grey moundstones and calcarenites indicative of the Grey Moundstone lithofacies (BG-1).

APPENDIX G

Schooner Cove (Mixed Biostrome and Oolite Sand Facies)

The cliffs at Schooner Cove, found at the north-east end of ~~Pointe au~~ (position G, Fig.8), show an exposed sequence from the Bradore Formation through to the Forteau Formation biostrome complex. Exposure of the biostrome complex is limited laterally except at the very top of the hill, but a useful, though incomplete sequence occurs (Fig.71).

The contact with the open shelf facies of the Forteau Formation is not seen but can be placed to within 1 m. The base of the biostrome consists of 3.76 m of Dolomitic Moundstone (RD-1), comparable to that at the north-east end of Fox Cove although no coelenterate occurs. This is overlain by 1.18 m of coarsely skeletal, partly oolitic packstone which becomes a purer oolitic grainstone towards the top. No sedimentary structures occur in this rock.

A thin (65 cm), poorly-exposed unit of grey, weathering orange-brown, moundstone with a mudstone matrix follows with a fauna dominated by stick-form archaeocyathids and reticulaminifera occurring with calcareous algae. This rock is comparable with the Grey Moundstone lithofacies (BG-1). It is overlain by skeletal, partly oolitic, partly oncolitic grainstone of thickness 1.30 m. The top 10 cm exposed (top is covered) consists of large (3 cm), brown weathering oncolites set in a skeletal, oolitic matrix. This bed may be thicker but the next 0.80 m is not exposed.

The sequence recommences with a large exposure of Grey Moundstone (BG-1) with laterally equivalent coarse skeletal calcarenite. Thick-walled wide cones and reticulaminifera with associated calcareous algae dominate the skeletal element. Trilobites (Bonnia) are present. The maximum exposed thickness is 1.96 m but neither the base nor top is exposed. A gap of 0.80 m is followed by a thin (20 cm) bed of poorly exposed skeletal packstone which grades upwards into a sequence of oolitic, skeletal grainstones associated with small bioherms, typical of the Oolite Bioherm Unit (BB). Less than 2.0 m of this unit is exposed vertically but widespread lateral exposures occur as the beds lie on the top of a hill. A total of 9 small bioherms, mostly of unknown maximum dimensions are partially exposed. The largest bioherm is 11 m by 5.5 m and 2 m high although the top is never seen. These bioherms consist of grey/green algal-archaeocyathid moundstones with a mudstone

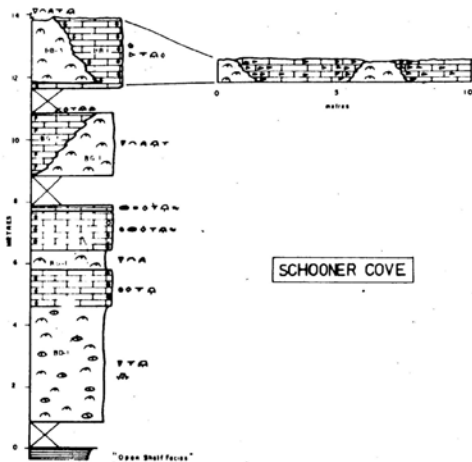


Fig. 71: Stratigraphic section in the mixed Biostrome Facies and Oolite Sand Facies at Schooner Cove.

matrix. The bioherms have a flat base with a strongly convex upper surface. Calcareous algae appears to be the dominant organism, with stick-form archaeocyathids, low-angle cones, and retilaminiforms common. The bioherms are surrounded by an apparently structureless but well-bedded assemblage of oolitic, skeletal grainstones. The contact with the bioherms is interdigitatory but no draping of the calcarenites occurs. Close to the bioherm, the oolitic grainstones show an abundance of Salterella cones which diminish in density away from the bioherm until, at about 3 m distance, they become scarce. This is seen on all sides of the bioherms and is not restricted to just one side.

APPENDIX II

L'Anse au Loup (Oolite Sand Facies)

Along the main road, to the north-east of L'Anse au Loup (position H, Fig.8), the Oolite Sand Facies is poorly and infrequently exposed so that no measured section could be obtained. However, rocks characteristic of the Oolite Sand Facies do occur there. These include mottled, dolomitic siltstones; oolitic, skeletal grainstones, and burrowed skeletal grainstones.

APPENDIX I

Archaeocyathids: Research and Distribution

Archaeocyathids are possibly the only major animal phylum to have become extinct (Hill, 1972). Their lack of descendants is reflected by the uncertainty of their affinity. They were regarded primarily as corals by the discoverer, Capt. Bayfield, in 1845, and later by Billings (1861), Bornerman (1886), and Hinde (1889). During the same period of time, however, they were also regarded as Protozoan (Billings, 1865) as foraminifera (Dawson, 1865; Meek, 1868) as sponges (Walcott, 1886; Taylor, 1910) as a receptaculitid (Roemer, 1878), and as calcareous algae (Van Toll, 1889). Taylor's work was apparently regarded as definitive as it was over 25 years later before the question of their affinity was again discussed when they were placed into a subphylum of the Porifera (Bedford and Bedford, 1939; Vologdin, 1937). They were first placed into a phylum of their own, the Archaeocyatha, by Okulitch and De Laubenfels (1953) and have maintained that status ever since (Hill, 1964; 1972) although several workers regard them as being so similar to the sponges as to not warrant a separate phylum (Ziegler and Rietschel, 1970; Balsam, 1973).

Although morphological variation is great, the most common form, an inverted cone, superficially resembles a rugose coral, but the similarity ends there. The archaeocyathid skeleton consists of 1 or, more commonly, 2 perforate walls which are connected by perforate radial plates and rods, imperforate dissepiments and tabulae or tubules (Hill, 1964). A cavity occupies the central part of the skeleton. The morphology varies from stick-like forms (sometimes branching), to bowl- and plate-like forms. Nothing is known of the soft tissues of archaeocyathids.

Stratigraphically, archaeocyathids range throughout the Lower Cambrian after which they became extinct. Most taxonomic and stratigraphic work has been done in Russia, particularly on the Siberian platform (Lena River section) and Altai-Sajan fold-belt where archaeocyathids are present throughout the Lower Cambrian strata from the earliest Tommotian through the Atdabanian, Lenian, and Elankian. Nowhere else in the world is there such a complete sequence (Rozanov and DeBrenne, 1974).

Early history of archaeocyathid research

Archaeocyathids were discovered on the south coast of Labrador in 1845 by Captain H.W. Bayfield, but were misidentified as a rugose coral Cyathophyllum (Bayfield, 1845). The first Russian discovery of an archaeocyathid was by a mining engineer, Meglisky, in 1850 along the Lena River section in Siberia, but it was identified as the Upper Carboniferous plant Calamites cannaeformis. The first scientist to collect archaeocyathids was Richardson of the Geological Survey of Canada. Unfortunately, his collection, all from southern Labrador, was lost as the ship, returning to Montreal with the specimens, sank. Only one specimen survived and was subsequently illustrated by Logan (1863).

The term archaeocyathid was derived by Billings (1861) who erected the genus Archaeocyathus, and named two species: A. atlanticus and A. minganensis, both from the Fordeau Formation in Labrador. A. minganensis was also found in the Ordovician age Beekmantown Group on Mingan Island in the Gulf of St. Lawrence. Billings (1861) first believed these forms to be corals but later changed his mind and designated them as protozoa (Billings, 1865). Much later, A. minganensis was found to be a sponge (Archaeoscyphia) but A. atlanticus was an archaeocyathid.

Present day distribution of archaeocyathids

World-wide distribution

Since 1861 archaeocyathids have been reported from every continent and substantiated in all but South America where they were described by Fergulio (1949) but refuted by Hill (1972).

By far the most extensive occurrences of archaeocyathids are in the USSR, and this has resulted in a vast amount of literature, mainly monographic, which is summarized by Hill (1964). The forms occur in two main areas; the Siberian platform, including the Lena River section, and the Altai-Sajan fold-belt. As archaeocyathids are present throughout the continuous Lower and lower Middle Cambrian sections in these regions, it has been suggested that four stratigraphic stages can be recognised using the development of archaeocyathids as the time control, and that these stages could serve as the basis for a division of the Lower Cambrian and world-wide correlation (Rozanov and Debrenne, 1974). The four stages recognised in ascending order are the Tommotian, Atdabanian, Lenian, and Elankian. The Elankian may, in

part, be Middle Cambrian (Rozanov and Debrenne, 1974). The only other Asian occurrence of archaeocyathids is from China (Blackwelder, 1904; Ogawa, 1905).

European occurrences of archaeocyathids are relatively few. Probably the best exposed outcrops are in Spain where 2 major localities are known, both in the north-west part of the country. Archaeocyathids are found in the Lancasa Formation of the Esla Valley where they are associated with oncolites and bioclastic debris (Debrenne and Zamarreño, 1970), and in the equivalent Vegadeo Formation in the region of Ponferrada, both of Lenian age (Debrenne and Zamarreño, 1975). The second occurrence is from Las Ermitas and yields an older, early Atdabanian age fauna (Rozanov and Debrenne, 1974).

In the Iglesias-Sulcis region of S.W. Sardinia, archaeocyathids occur in algal bioherms and within clastic strata of the Matoppa member of the Nebida Fm. (Debrenne, 1964; Brasier, 1976). A Lenian or possibly Upper Atdabanian age is indicated by the assemblages (Rozanov and Debrenne, 1974).

Two poor exposures are found in France. Lenian archaeocyathids are found in the 'Calcaire à Archaeocyathus' of the Montagne Noir area (Debrenne, 1974), while a poor fauna, possibly of Atdabanian age (Rozanov and Debrenne, 1974), is found in Carteret, Normandy (Debrenne, 1964).

In N. Norway, on the Isle of Sørøya, archaeocyathids have been reported within a highly deformed, metamorphosed sequence occurring in rafts of calc-silicate rocks within the Storelv Gabbro (Holland and Sturt, 1970). As they are so badly preserved, they can only be placed down to the order Ajacicyathida.

The most recent European discovery of archaeocyathids was at Inchnadamph in N.W. Scotland where they occur as rare fragments in silicified dolomite clasts, 10 m above the base of the Eilean Dubh Formation of the Durness Group, and assigned, in this preliminary study, to the family Ajacicyathacea (Brasier, 1977).

Archaeocyathids have been reported from the Middle Cambrian of the Holy Cross Mountains in Poland (Orłowski, 1959; 1960) but have since been re-interpreted as the blastozoan echinoderm class Ctenocystoidea (Sprinkle, 1973, p. 111).

Archaeocyathids have been reported from erratics in

the Dwyka Tillite in S. Africa (Rozanov and Debrenne, 1974), but the major African occurrence is in Morocco where Lower Lenian forms are found from the slopes of the Anti-Atlas Mountains (Rozanov and Debrenne, 1974) and also in older, Middle Atdabanian (possibly Tommotian) rocks in the "Schisto-Calcaire" succession of the north slope of the Anti-Atlas (Debrenne, 1964) where they occur in bioherms (Debrenne, 1975).

Extensive archaeocyathid bearing beds are found in the Flinders Range of Australia, described by Taylor (1910) and subsequently revised by Debrenne (1970; and the Ajax Mine fauna, 1974). Aspects of the paleoecology are discussed by Brasier (1976). Two levels of archaeocyathids are found in the Flinders Range. The lowest is the Wilkowillina Limestone of Atdabanian age and the uppermost is the Wirreolpa Limestone of Lenian age (Rozanov and Debrenne, 1974).

In Antarctica, there was a 50 year gap between the discovery of archaeocyathids in glacial erratics (Priestly and David, 1910) and of their in situ discovery (Laird and Waterhouse, 1962) and subsequent documentation (Hill, 1965). A possible Atdabanian or Lenian age has been proposed for this fauna (Rozanov and Debrenne, 1974).

The genus Archaeocyathus is illustrated, amongst other fossils, from the Ella Formation of the East-Central Greenland fold-belt where they occur in large numbers (Poulsen, 1932).

North American occurrences

The distribution of archaeocyathids in North America can be divided into two distinct geographical areas: the Western Cordillera and the Appalachians.

The Western Cordillera: The Western Cordillera of Canada has numerous reports of archaeocyathids which are listed and well-referenced by Stelck and Hedinger (1975). They occur in a linear belt approximately 1200 kms long and 250 kms wide, trending N.N.W. - S.S.E. (Stelck and Hedinger, 1975; p. 2015) which presumably extends into the U.S.A. where they have been described from Washington State (Okulitch and Greggs, 1958). A well-documented occurrence from the McKenzie and Cassiar Mountains of the North-West Territories, the Yukon, and British Columbia (Handfield, 1971) gives a Sinoshtyngol age when correlated with the Altai-Sajan fold-belt of Russia, but Rozanov and Debrenne (1974) suggest a younger, Lower Lenian age when

6

correlated with the Siberian Platform. The occurrence of archaeocyathids in bioherms is often mentioned from the Canadian Cordillera (e.g. Brabb, 1967; Fritz, 1974) but they have not been described in detail.

In the Great Basin Silver Peak Range of W. Nevada and the White and Inyo Mountains of California, archaeocyathids occur within a 6,000 ft. (1828 m) thick Lower Cambrian sequence which is part of a continuous section from the late Precambrian to the late Cambrian (McKee and Gangloff, 1969). The archaeocyathids, which occur in the middle one-third of the sequence, have been correlated with the Lenian stage of the Siberian Platform (Rozanov and Debrenne, 1974). They form bioherms less than 100 ft. (30 m) long, 5 ft. (1.5 m) high in the Montenegro Member of the Campito Formation and the lower part of the Harkless Formation, and occur as isolated individuals in the intervening Poleta Formation (McKee and Gangloff, 1969; Morgan, 1976).

The Appalachians: Isolated occurrences of archaeocyathids are documented throughout the Canadian and U.S.A. Appalachian Mountain system.

The northernmost occurrence is from the Fordeau Formation of southern Labrador, eastern Quebec, and N.W. Newfoundland (Schuchert and Dunbar, 1934; James and Kobluk, 1978; Cumming, in press). These are probably the best exposures of such rocks in the Appalachian system, partly because they are exposed to the west of the western limit of Appalachian deformation.

The only reported occurrence of Middle Cambrian archaeocyathids in North America is from the St. John Group at St. Martins in New Brunswick and are allied to the Atlantic Province faunas (Okulitch, 1943).

Fragments of archaeocyathids have been reported from limestone blocks in the Bic Conglomerate at Bic Harbour, Quebec (Okulitch, 1943).

In the northern U.S.A., archaeocyathids are known from the Schodack Formation to the north-east of Troy, New York State (Ford, 1873; Okulitch, 1943), and from York Co., Pennsylvania (Stose and Jonas, 1939). They have recently been described as occurring as scattered individuals and in small bioherms from the base of the Leithsville Formation in New Jersey, and subsequently correlated with the Fordeau Formation (Palmer and Rozanov, 1976).

Archaeocyathids have long been known from the Shady

Dolomite and Weisner Formation in the southern Appalachians. Archaeocyathid "reefs" were described from Austinville, Virginia (Resser, 1938). These structures have been re-investigated and re-interpreted as burrow complexes (Balsam, 1970; 1974) although isolated archaeocyathid individuals are present in the area (Balsam, 1974; Willoughby, 1976). Archaeocyathids were also reported from the Shady Dolomite in Georgia (Kesler, 1950) and Alabama (Butts, 1926).

The most recently documented occurrence is from the Valley and Ridge "Sleeping Giants" Province which is part of the Coosa deformed belt near Talladega, Alabama, where small mounds and individuals are reported (Bearce and McKinney, 1977).

Archaeocyathids as "reef"-builders

Compared with the vast amount of literature on the taxonomy of archaeocyathids, notably by workers in the USSR, very little research has been aimed towards an understanding of the paleoecology of the organisms, particularly as to their role as Cambrian reef-builders.

Archaeocyathids are recognised as occurring in biohermal structures in many places (see previous section on distribution), but these structures have not been described in any detail. Debrenne (1959) recognised three modes of occurrence of archaeocyathids; as isolated individuals associated with other organisms such as trilobites, brachiopods, and hyolithids; in laterally continuous banks (biostromes); and in bioherms having topographical relief and sometimes associated with calcareous algae.

Zhuravleva (1960; 1966) recognised a variety of archaeocyathid biohermal structures from the Siberian Platform and suggested that the distribution of archaeocyathids was depth controlled (in Hill, 1972, p. E. 28). She claimed that small bioherms flourished at depths of 20-30 m and down to 50 m. This idea was based on the association of the archaeocyathids with the calcareous alga *Renalcis*. When archaeocyathids are found associated with the calcareous alga *Epiphyton*, then depths of 50-100 m are suggested (Zhuravleva, 1960; in Hill, 1972).

Archaeocyathid (organogenic) build-ups from the Altai-Sajan fold-belt of Russia have been classified into four structures (Zadorozhnaya, 1975); biostromes, bioherms, biohermal massifs, and reefs. The distribution of these structures in both time and tectonic setting is also noted.

In North America, Okulitch (1969) doubted the potential of archaeocyathids to form reefs unless accompanied by algae. However, he recorded 'colonies' of the organisms in structures with lateral dimensions of up to several miles but with vertical expressions of only a few feet.

Biohermal structures have long been known from the White and Inyo Mountains of Eastern California (McKee and Gangloff, 1969) where they form lense-shaped limestone beds 100 ft. (30 m) long and 5 ft. (1.5 m) high with primary topographical relief. The maximum thickness observed by McKee and Gangloff is 18 ft. (5.5 m), but from the same area and formation (Montenegro Member of the Campito Formation), lenticular mounds of 194 m long with thicknesses of 10 m are recorded (Morgan, 1975). These structures are mud-supported with the mud supposedly derived from the breakdown of algal thalli, a situation analogous to the carbonate banks of Florida (Morgan, 1975).

The only detailed work on archaeocyathids from both a sedimentological and paleontological view deals with the "patch-reefs" of the Forbeau Formation in southern Labrador (James and Kobluk, 1978). It has emerged from their study that features which characterized modern reefs such as biological accretion, internal sedimentation, early lithification, and biological destruction can be recognised in these Cambrian structures. These patch-reefs consist of loaf-shaped mounds of archaeocyathid-rich mudstone along with Renalcis and are stacked on top of each other and flanked by skeletal calcarenites and shales (James and Kobluk, 1978).

Fig.72. Geology of the study area between Lourdes de Blanc Sablon (Québec) and West St. Modeste (S. Labrador)

Key

CAMBRIAN

Forteau Formation



OOLITE SAND FACIES oolites, calcarenites



BIOSTROME FACIES moundstones



PATCH-REEF FACIES AND OPEN-SHELF FACIES patch-reefs, calcarenites, siltstones, shales, dolomite

Bradore Formation



BRADORE SANDSTONE conglomerates, sandstones

PRECAMBRIAN



GRENVILLE BASEMENT gneiss, granites, schists



geological contact



fault



facies contact



geographical boundary



road



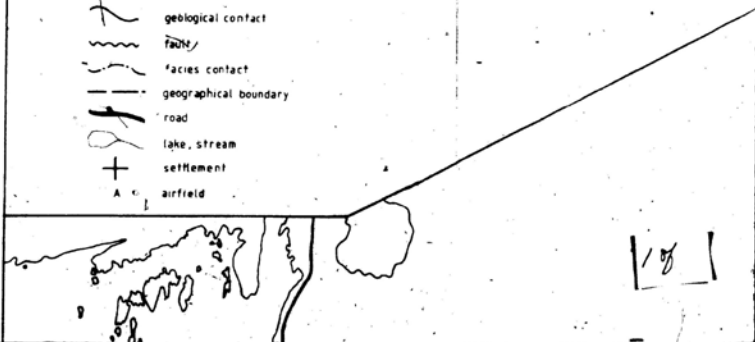
lake, stream



settlement



airfield



Sablon (Québec)

ACIES mounds, stones, calcarenites

tones, shales, dolomites

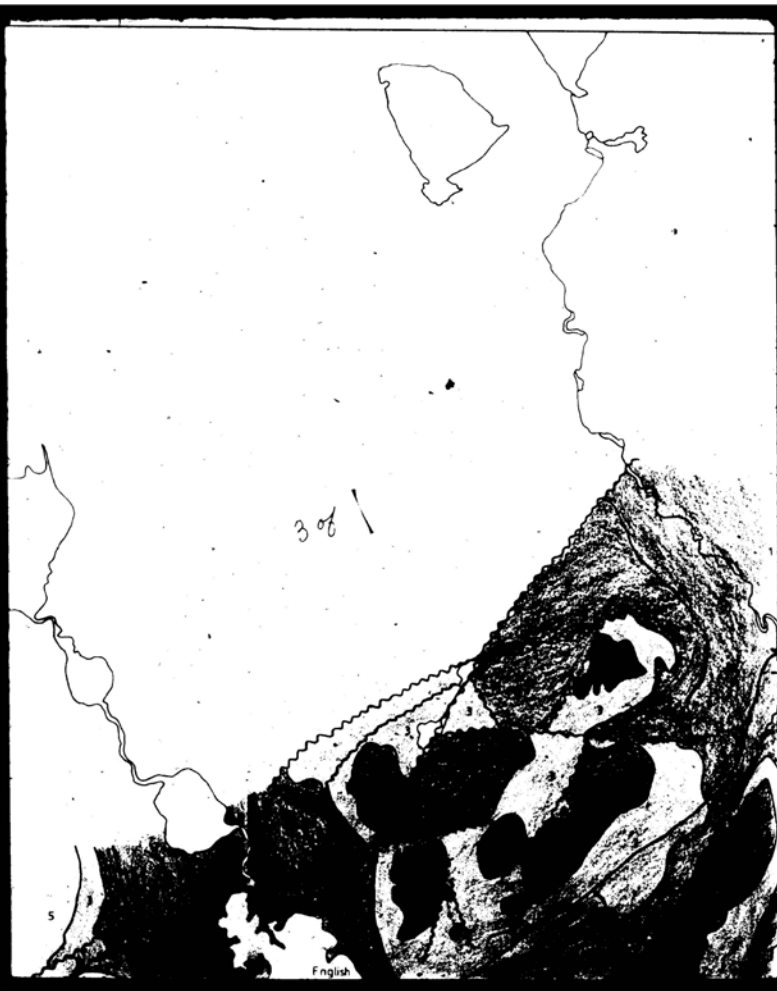
N

SCALE 1:50,000

1 KM

NEWFOUNDLAND
QUÉBEC

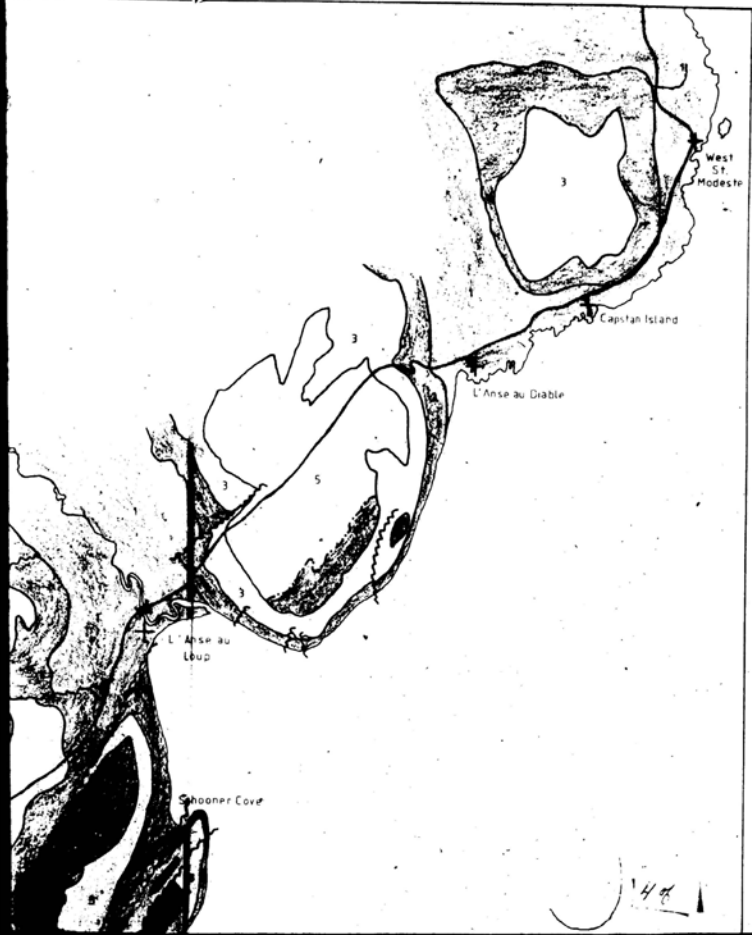
24

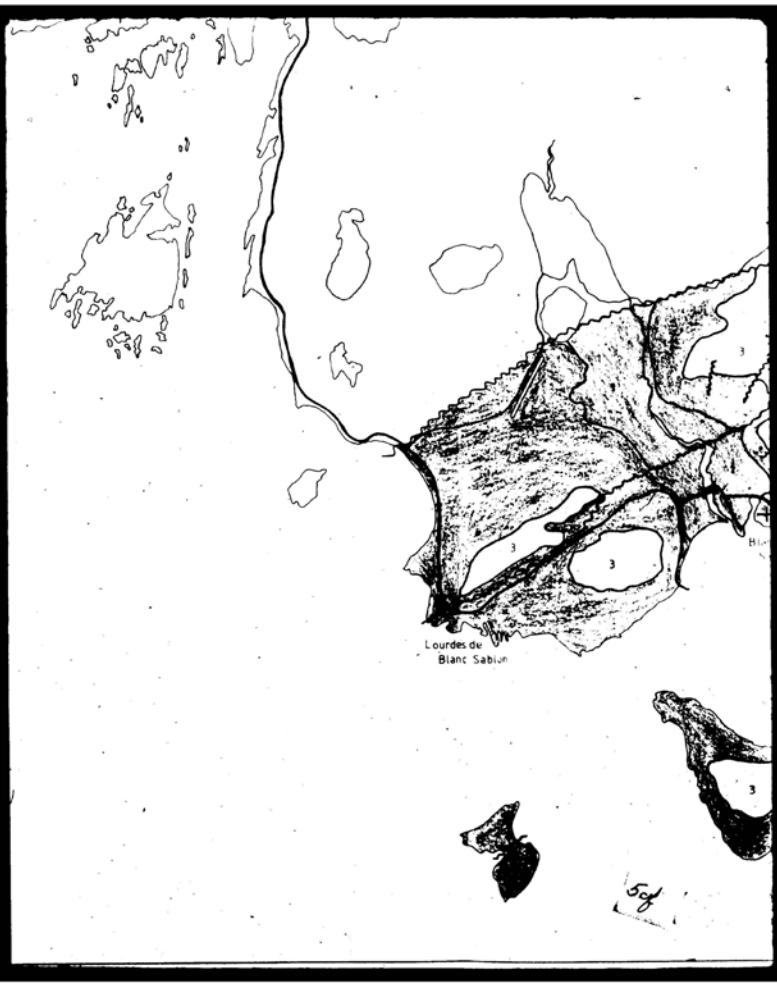


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English





Lourdes de
Blanc Sablon

59



STRAIT OF BELLE

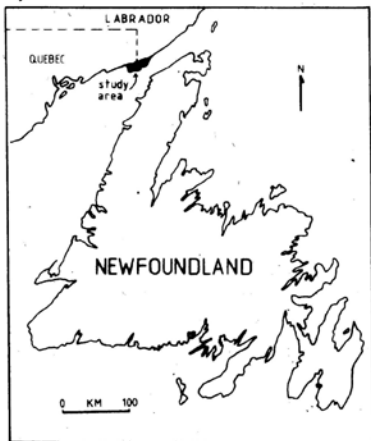
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BELLE ISLE

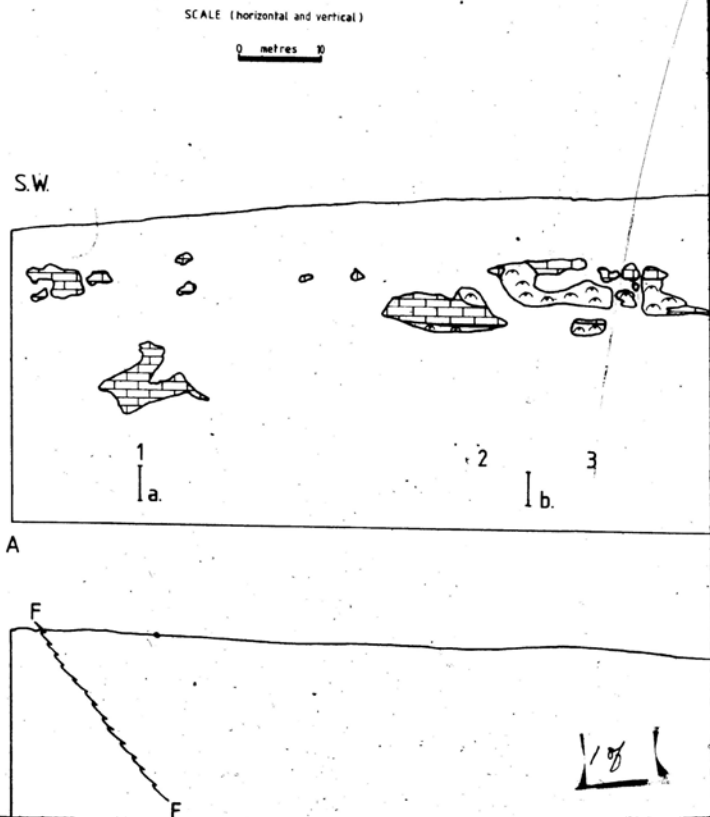
74

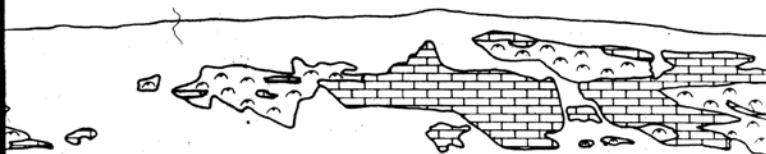
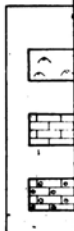
Pointe Amour



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Fig. 73. Facies relationships of exposed strata at Osprey Reef





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5

6

BIO STROME FACIES OOLIT



24

KEY



MOUNDSTONE (BR-1)



SKELETAL CALCARENITE (BR-2)

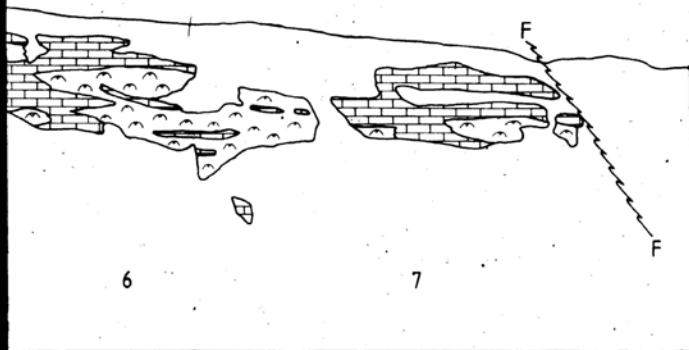


OOOLITE SAND FACIES

1-12 SECTION NUMBER (see text)

I a.-d. MEASURED SECTIONS
(see fig 66)

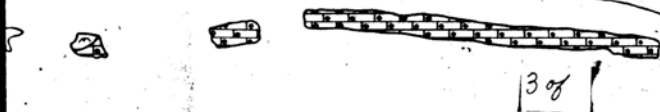
F FAULT



B

MOUNDSTONE FACIES OOOLITE SAND FACIES

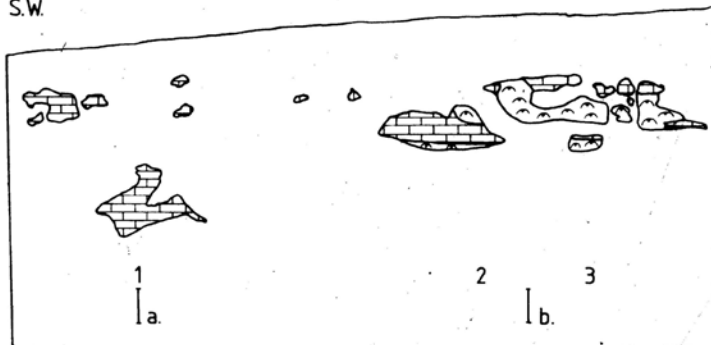
N.E.



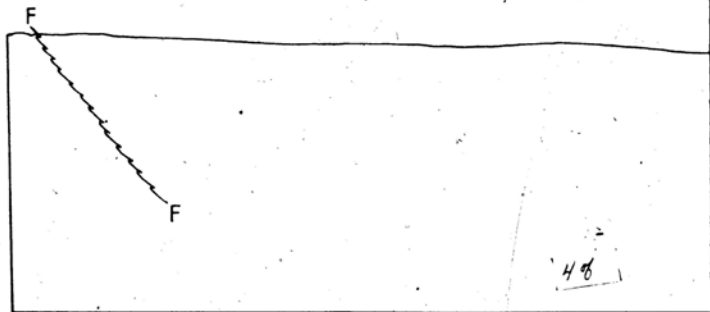
3 of 4

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S.W.

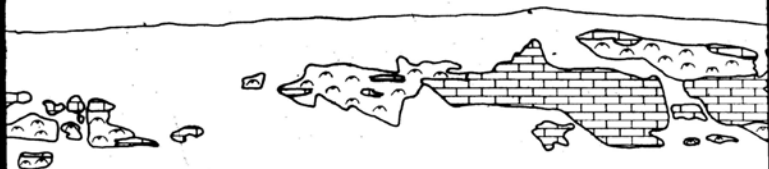


A



B

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4

5

1

BIO STROY



8

150g



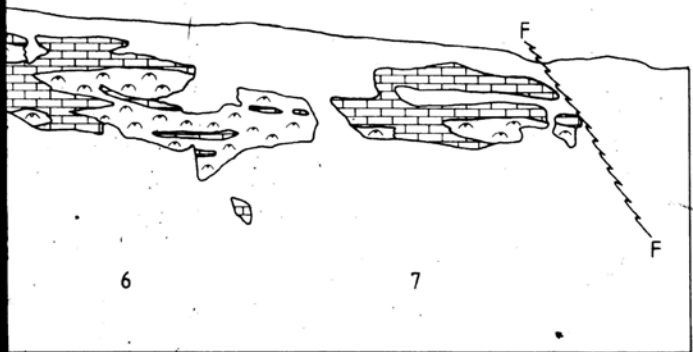
DIRECT THE EXPERIMENTAL FOR FIG. 56

1d.-d.

REWORKED SECTION
(see fig 66)



OOLITE SAND FACIES

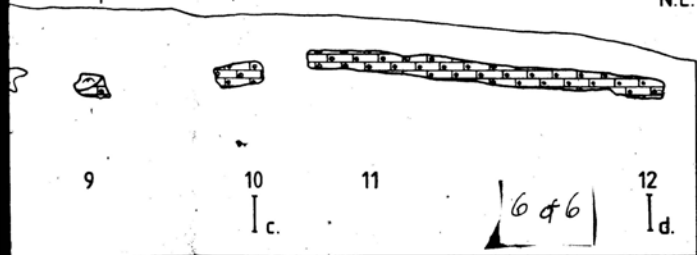


B

STROME FACIES

OOLITE SAND FACIES

N.E.



C

